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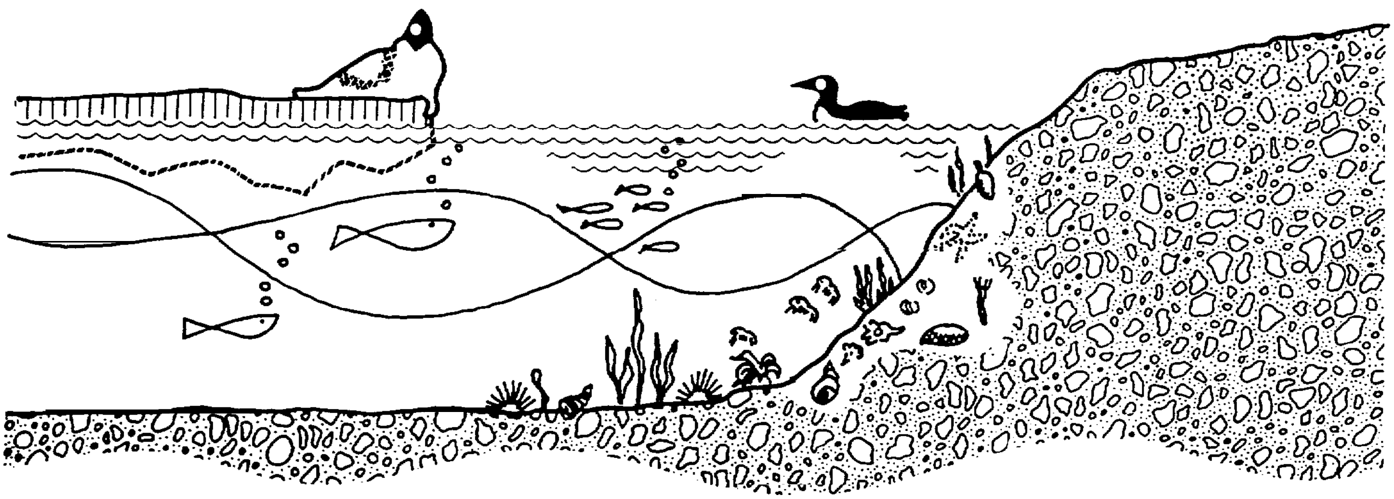
SHORELINE COUNTERMEASURES



BIOS CAPE HATT

Baffin Island Oil Spill Project

WORKING REPORT SERIES

1980 STUDY RESULTS

BIOS Working Report Series

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Final Report

Baffin Island Oil Spill Project
Shoreline Component

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ABSTRACT

A small, controlled, oil spill experiment was conducted during August 1980 on the northern coast of Baffin Island, N.W.T., to investigate the fate of stranded oil in an arctic environment. This experiment involved a single oiling of eight test plots using an aged crude oil and a water-in-aged crude oil emulsion. The oils were spilled on backshore and intertidal test plots of varying wave exposure and sediment character; beach morphology and oil-in-sediment concentrations were monitored for an 8-day period following each spill. Within 24 to 48 hours of the application of oil to the exposed ("high-energy") test beach plots, much of the oil (50-90%) was removed as a result of mechanical wave action. On one plot on this beach, some of the oil was buried by beach accretion during this time period. Tidal water movement removed from 30 to 90% of the oil from the sheltered ("low-energy") test beach plots despite the lack of mechanical wave action at that site. At the sheltered site the plots differed in terms of texture characteristics. Lower oil retention values were recorded on the plot with fine sediments, which also had a high groundwater table, than on the coarse-sediment beach plot. Variations in the retention results between plots can be attributed in part to the poor adhesion properties of the emulsified oil.

Comparison of the weathering characteristics of the two test" oils, the aged crude oil and the water-in-aged crude oil emulsion, is complicated by important variations in coastal processes and sediment characteristics, which occurred over relatively small distances (<10 m). The design of future oil spill experiments and their associated sampling programmed should recognize the complexity of natural processes operating in the shore zone. A second significant variable is the uneven micro-topography of the beach surface, which results in the pooling of oil in depressions and in thinning or runoff from small ridges or other high spots, such as cobbles. Differences in analytical results between and within plots can be attributed in part to the non-uniformity of (a) the oil distribution on the surface of the plots, and (b) differences in the physical and chemical characteristics of the available test oil.

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The Baffin Island Oil Spill (BIOS) experiment is a study programme designed to replicate the effects of a large-scale oil spill in an arctic environment. Initial phases of the experiment were conducted at Cape Hatt on the northern shores of Baffin Island during the summer of 1980. As a component of the study, the Phase I Shoreline Test Programme was designed (1) to prepare controlled oil plots in order to determine the natural weathering or fate of crude oil on arctic shorelines over a three-year period, and (2) to test methods of spilling oil on shorelines in preparation for the countermeasure tests to be conducted during the Phase 11 Test Programme in 1981.

1.1 Experimental Design

In order to evaluate the weathering characteristics of spilled oil in the Arctic, two different forms of the same oil (Lago Medio) were spilled on several test plots located on representative shoreline segments. The two forms of the oil were (1) a weathered or aged crude oil that had 8 percent of its light ends evaporated, and (2) a water/oil emulsion consisting of 50 percent water and 50 percent aged crude oil. Each of the spill locations included an aged crude oil plot and an emulsified crude oil plot, thereby permitting comparison of the weathering and dispersal characteristics between the two oil forms under similar environmental conditions.

Eight spill locations were chosen to represent different types of shoreline environments as well as to provide control plots for comparing the effectiveness of marine versus atmospheric processes in removing the oil (Table 1.1). Two intertidal test plots (H-1 and H-2) were located on the open eastern coast of Cape Hatt, which is exposed to relatively high wave-energy levels and which is representative, in terms of wave exposure and sediment texture, of “open” coasts in the Canadian Arctic. The other

TABLE 1.1 Summary Table

	PHYS	AL CHARACTERI	ICS			SPILL CH	CTERISTICS				
PLOT	DIMENSIONS	LOCATION	WAVE EXPOSURE	SEDIMENT CHARACTERISTICS	MAXIMUM SLOPE	TYPE OF OIL	AMT. APPLIED (m^3)*	(Gal)*	% OIL RETAINED	SEDIMENT HYDROCARBON CONTENT % INITIAL	AFTER 8 DAYS
N-1	4 x 10 m	upper inter-tidal zone, open coast	Nigh, Fetch >90 km	Gravel, Sand, Pebble	10"	Aged Crude	0.41	90	89	2.44	0.56
N-2	4 x 10 m	upper inter-tidal zone, open coast	Nigh, Fetch >90 km	Gravel , Sand, Pebble	10"	50% water/ oil emulsion	0.41	90	89	1.21	0.0004
L-1	4 x 10 m	upper inter-tidal zone, Z-Lagoon	Low, Fetch <2 km	Sand, Pebble	9°	Aged Crude	0.41	90	62	1.63	1.02
L-2	4 x 10 m	upper inter-tidal zone, Z-Lagoon	Low Fetch <2 km	Cobble, Pebble, Silt, Sand	7"	50% water/ oil emulsion	0.20	45	38	0.24	0.010
T-1	4 x 10 m	Control plot back-shore, Z-Lagoon	None	Sand, Pebble (Shingle)	~5°	Aged Crude	0.41	90	80	3.16.	4.14
T-2	4 x 10 m	Control plot back-shore, Z-Lagoon	None	Sand, Pebble (Shingle)	~5"	50% water/ oil emulsion	0.41	90	83	1.42	5.90
TE-1	2 x 2 m	Control plot back-shore, open coast		Cobble, Pebble Sand	<5°	Aged Crude	0.02	~5	?	3.78	4.58
TE-2	2 x 2 m	Control plot back-shore, open coast		Cobble, Pebble Sand	<5°	50% water/ oil emulsion	0.02	<5	?	2.64	2.92

* refer to Table 5.2 (page 5.8)

two intertidal test plots (L-1 and L-2) were located on the shoreline of a sheltered, low wave-energy environment (Z-Lagoon). Four control test plots (T-1 and T-2; TE-1 and TE-2) were established in backshore areas not affected by tidal, wave, or ice action. The control plots will permit a comparison of oiled sediment weathering affected by atmospheric weathering only versus that affected by tidal, wave, and ice action.

1.2 Oil Application

In order to approximate a large spill stranding on the shoreline, oil was applied to the test plots in a relatively even coating with a thickness of 1 cm for the aged crude oil and 2 cm for the water/oil emulsion. Oil was applied to each test plot using an oil application system consisting of an oil drum mounted on the back of an ATV (all-terrain vehicle) and connected by hoses and a pump to an oil distributor bar mounted below the drum; as the ATV traversed the test plot (traverse speed approximately 10 m/min), oil was spilled behind the vehicle. The system performed well on beaches of various slope and sediment texture (Table 1.1).

An application of 0.4 m^3 (90 Imp. gal) per test plot provided approximately 1 cm thickness of oil on the plot; however, due to surface runoff during and immediately after the application, considerably less than 0.4 m^3 (90 Imp. gal) of oil was retained on the plot. On most plots, oil retention was within 80 percent of the design amount, but on the low-energy plots, where the groundwater table was high, oil retention was poor (Table 1.1).

1.3 Preliminary Observations of Spilled Oil

Observations of beach morphology changes were noted and oiled sediment samples were collected for a two-week period following the application of oil to each of the test plots.

Estimates of sediment hydrocarbon content (Table 1.1) generally supported observations made in the field. The significant observations regarding the Phase I Shoreline Test Programme are:

- An apparent high variability in control plot oil contents resulted from non-uniform distribution of oil on the plot, and, to a lesser extent, variation in sampling techniques.
- Oil was effectively removed from the exposed beach plots (H-1, H-2) as a result of mechanical wave action on the shore; within 48 hours of the spill, wave action had effectively removed 50% to 90% of spilled oil from the beach sediments, although locally a relatively thick oiled sediment layer (up to 20 cm) was buried (up to 30 cm) due to sediment deposition on the beach face.
- Tidal action alone proved to be effective in removing oil from fine-sediment beaches not exposed to wave action; on Plot L-2 (low-wave energy, emulsified oil plot), fine beach sediments and high groundwater tables facilitated the removal of oil by tidal action and 90% of the oil was removed during the brief 8-day observation period.
- Tidal action was relatively ineffective in removing oil from coarser grained, protected beaches where up to 65% of the oil remained on the beach after the observation period.
- The emulsified oil plots showed a lower oil retention than did the aged oil plots; this trend was partially due to the poor adhesive properties of the emulsified oil, however, variations in beach response and sediment texture between the emulsified and aged oil plots were also responsible for producing the observed differences in oil retention. Plot H-2 (emulsified oil) showed greater amounts of erosion during the observation period than did H-1 (aged oil), and sediment texture was finer (with correspondingly higher water tables) on L-2 (emulsified oil) than on L-1 (aged oil). Thus , the observed differences in oil retention were not entirely due to differences in physical characteristics.

1.4 Recommendations for Further Study

Although some of the results discussed here are preliminary and may require some minor revision, it is apparent that some minor changes in the experimental design will improve future results. Some of the suggested revisions include:

- The oil application system proved to be flexible and perform well in the range of experimental test plots selected. No major changes to the system are necessary although increased uniformity in oil application rate is desirable; greater uniformity may be achieved by: (a) increasing the speed of the ATV across the test plot, or (b) winching the ATV across the plots at a more uniform rate.

- Future experimental test plot selection should be made with considerable caution. The initial observations of oil runoff and of beach morphology changes indicate that the intertidal test plots at both the high- and low-energy sites contained important if not subtle differences which resulted in variable oil retention characteristics. The observed differences in sediment oil retention between the two oil forms (Table 1.1) were due partially to differences in beach morphology response between the two plots, and partially to differences in physical characteristics of the two oil forms. Ideally, the replicate plots should have similar oil retention characteristics and should respond similarly to environmental processes.

- Additional samples should be collected from the control plots to better define oil retention and weathering characteristics. Considerable variability existed in the test plot hydrocarbon contents as a result of non-uniformity of the oil application (Table 1.1, see also Figs. 6.1 and 6.2 in main text). Additional samples would partially alleviate the problems in non-uniform application and would allow more reliable estimates of the variation of sediment hydrocarbon content in time. Trends in the sample data suggest each sample should be comprised of approximately 20 subsamples.

- Consideration should be given to a more extensive monitoring programme following the spill in order to define the particular event or events that are responsible for removing the oil from the test plots. Particularly, the effects of freeze-up and ice scouring on the present test plots are unknown.
- The mode of origin of "ice mounds" in the intertidal zone is uncertain and the process by which this ice form develops may be significant in terms of the fate of stranded oil. A pre-melt spring observation programme is recommended in order to determine the cause of ice-mound formation and, if necessary, a follow-up instrumentation programme could be conducted to monitor those processes responsible for the development of this intertidal ice body.

2.0 INTRODUCTION

The Baffin Island Oil Spill (BIOS) experiment is a study designed to evaluate the long-term effects of spilled oil on arctic shorelines. The first phase of this study was conducted at Cape Hatt on the northern shores of Baffin Island (Fig. 2.1) during the summer of 1980, and included a number of components in addition to the shoreline component described in this report. The primary goals of the Phase I Shoreline Test Programme were: (1) to prepared controlled oil spill plots in order to determine the natural weathering or fate of crude oil on arctic shorelines over a three-year period, and (2) to test methods of spilling oil on shorelines in preparation for the countermeasures tests to be conducted during the Phase II Test Programme in 1981.

The specific objectives of the Phase I Shoreline Test Programme were:

- to replicate the effects of a large oil spill by spilling oil on selected experimental test plots, and
- to evaluate the persistence and weathering characteristics of two forms of oil (aged crude oil and emulsified crude oil) on shorelines of differing wave-energy levels and ice-scouring activity.

The test procedure consisted of spilling oil on several shoreline test beaches of varying sediment composition and wave-energy levels, and subsequent monitoring of physical and chemical changes of both the oil itself and the surrounding environment.

This report focusses on a preliminary assessment of the Phase I Shoreline Test Programme and includes:

- a physical description of sites selected for the controlled oil spill experiments,
- a description of the actual procedures used in spilling the oil,

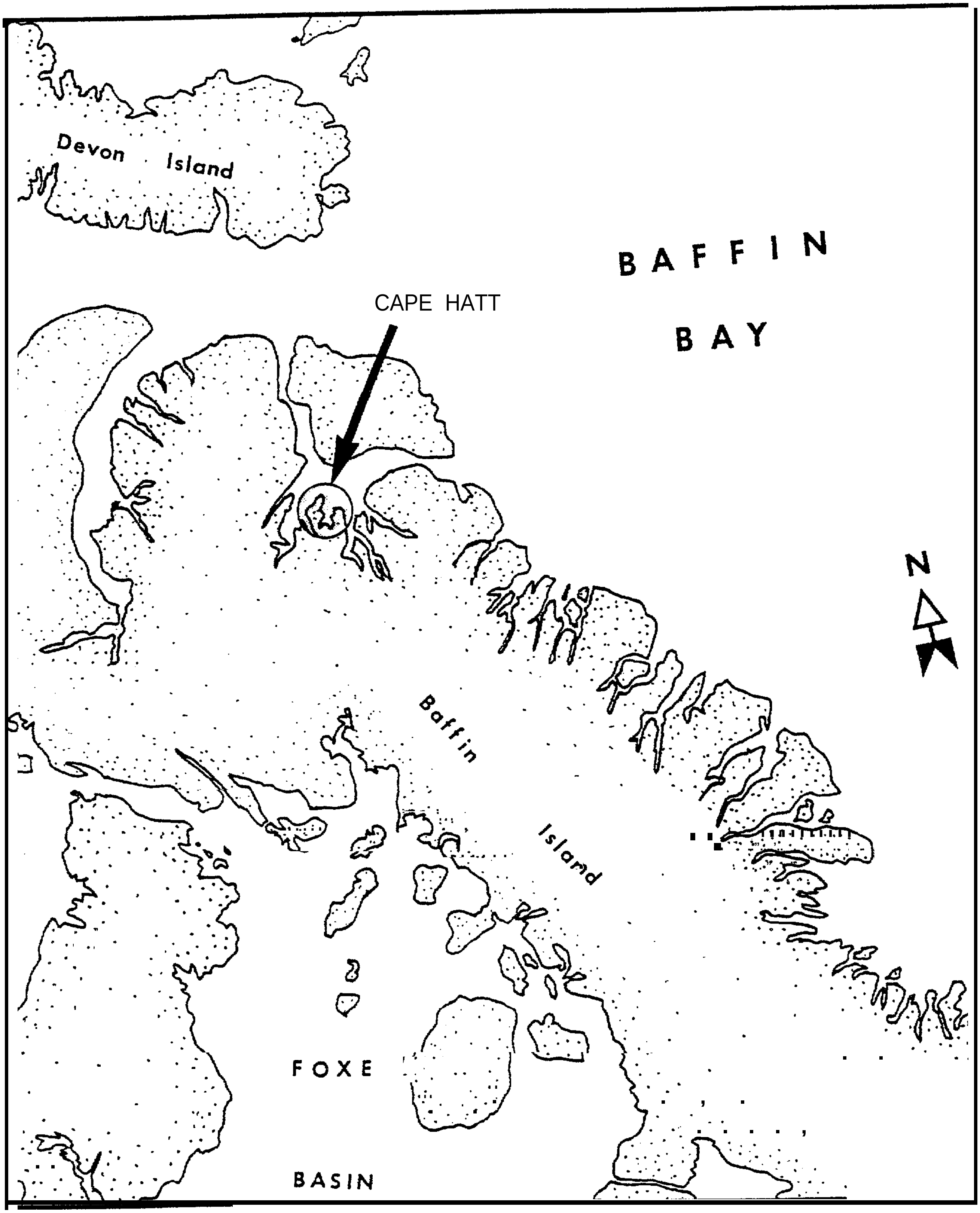

Figure 2.1 Location of Cape Hatt, Baffin Island.

- an evaluation of the effects of oil on the subsurface ground temperature regime, and
- a preliminary assessment of the fate of spilled oil on shorelines as a function of natural processes such as wave and tide action as well as atmospheric weathering.

The programme not only established a preliminary data base for the long-term analysis of spilled oil on arctic shorelines, but was also useful in providing a test of the logistical problems associated with spilling the oil with the limited equipment available. The results and experience obtained from the Phase I Test Programme will provide the basis for recommendations for the large-scale experiments to be conducted during the summer of 1981.

3.0 EXPERIMENTAL DESIGN

A brief review of the overall experimental design of the Shoreline Test Component is included in this section in order to provide a prospectus of the methodology used in meeting the experimental objectives. As mentioned above, the objectives were to replicate the effects of a large oil spill in the experimental test area and to evaluate the weathering characteristics of spilled oil on low- and high-energy shorelines. The detailed methodology used to meet these objectives is described below.

3.1 Test Setup

Eight test plots were used for the weathering experiments (Fig. 3.1). Two intertidal text plots (high energy: 4 x 10 m) were located on the open coast shoreline (eastern shore) of Cape Hatt; two additional intertidal test plots (low energy: 4 x 10 m) were located on the shoreline of Z-Lagoon; and four control plots were established in areas not actively affected by marine processes or ice scour. Table 3.1 lists the test plot parameters. The intertidal test plots (one crude oil and one emulsified oil) were located in the upper intertidal zone of the high- and low-energy test areas, where tidal action and ice scouring action would impinge on the plots. The plots extended approximately 0.5 m landward and 3.5 m seaward of the high-tide line. The control plots allowed comparison of oiled sediment weathering characteristics affected by tidal, wave, and ice action versus atmospheric weathering only. The test plots were staked and mapped (see Section 7.0) so they can be easily relocated and sampled in subsequent years.

3.2 Preparation of Oils

Two forms of the same oil (Lago Medio supplied by Texaco Canada, Ltd.) were used in the programme; crude oil aged 8 percent by weight and a water-in-oil emulsion prepared at the Cape Hatt test site by mixing equal volumes of seawater and aged crude oil. The resulting mixture was recirculated

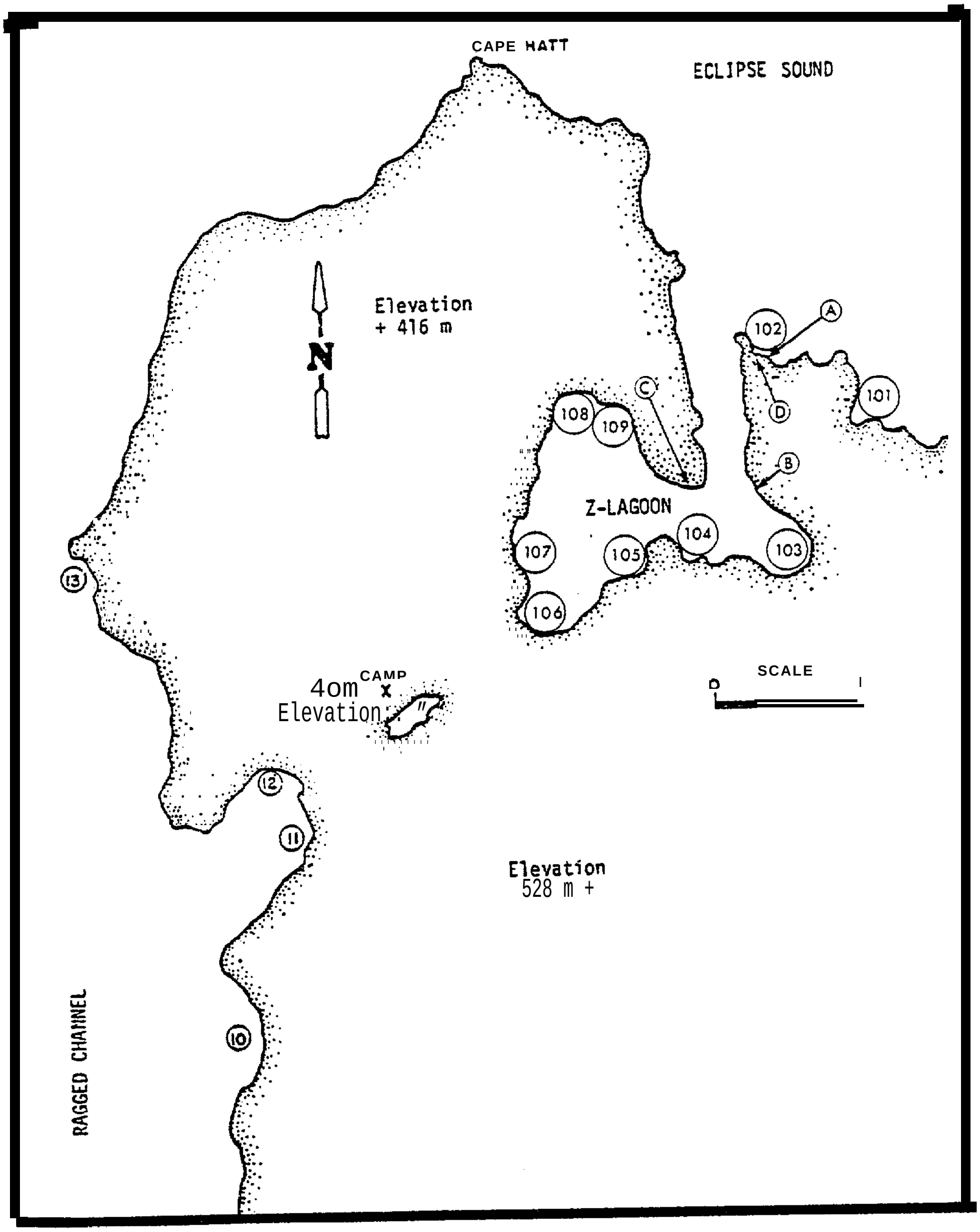

Figure 3.1 The Cape Hatt field area showing the location of the test plot sites: (A) the high-energy site, plots H-1, H-2, (B) the low-energy site, plots L-1, L-2, (C) the control test site, plots T-1, T-2, and (D) the high-energy back-shore site, plots TE-1, TE-2. The circled numbers indicate experimental bay locations.

TABLE 3.1 Test Plot Parameters

TEST PLOT #	TEST AREA	SITE	TYPE OF OIL SPILLED
H-1	40 m^2	upper intertidal area, open coast, high energy	aged crude
H-2	40 m^2	upper intertidal area, open coast, high energy	50% water/oil emulsion
L-1	40 m^2	upper intertidal area, Z-Lagoon, low energy	aged crude
L-2	40 m^2	upper intertidal area, Z-Lagoon, low energy	50% water/oil emulsion
T-1	40 m^2	control plot, backshore area	aged crude
T-2	40 m^2	control plot, backshore area	50% water/oil emulsion
TE-1	4 m^2	control plot, micro-biology studies	aged crude
TE-2	4 m^2	control plot, mocro-biology studies	50% water/oil emulsion

through a pump and back into a tank until the desired emulsion was created. Section 5.0 includes a detailed description of the emulsification system.

3.3 Test Procedures

In order to approximate a large oil spill stranding on the shoreline, oil was applied to the test plots in a relatively even coating with a thickness of 1 cm for the weathered crude and a thickness of 2 cm for the water-in-oil emulsion. Oil application generally occurred at approximately mid-tide on a rising tide cycle. Figure 3.2 shows the layout of an inter-tidal test plot.

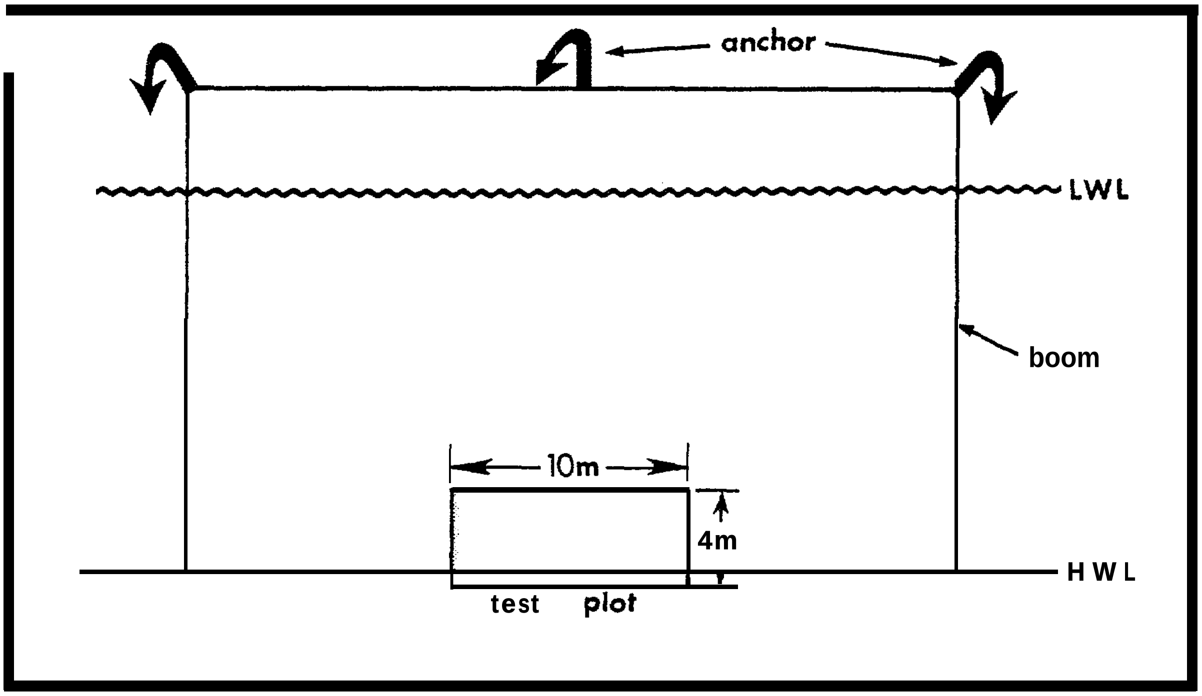

Figure 3.2 Plan of the intertidal test plot layout.

Oil was applied to each 4 x 10 m test plot using an oil application system consisting of an oil drum mounted on the back of an ATV and connetted by hoses and a pump to an oil distribution pipe mounted on the rear of the ATV. The ATV traversed the test plot and oil was spilled behind the vehicle. The speed of the ATV was controlled as it passed over the plot in order to maintain the desired oil thickness of 1-2 cm. A more detailed description of the system is included in Section 5.0.

3.4 Oil Spill Contingency Measures

Specific control measures were taken prior to application of the oil to the intertidal test plots. These measures were designed to minimize the spread of oil from the spill site and included:

- a plastic sheet drip pad at the end of each plot to catch dripping oil from the ATV distributor pipe (Fig. 3.3),
- a plastic sheet-lined trench at the base of each plot for collecting the oil that ran off immediately after the application (Fig. 3.3),

Figure 3.3 Photograph of test plot L-1 prior to oiling, showing the runoff collection trench at the base of the plot as well as a plastic drip sheet in the foreground.

- a booming configuration to contain oil floating on the water surface (see Figs. 3.2 and 3.4),
- a Morris MI-30 skimmer on a collection barge at the test site to skim oil inside the boomed area, and
- two bales of sorbent pads and two bales of sorbent booms at each test site.

All contingency equipment was in place before the oil application commenced and remained at the site for two flood-tide cycles. The oil boom and skimmer system was not used at the high-energy site because large waves, which were present during the spill, would have rendered the boom ineffective.

Figure 3.4 Photograph of the booming configuration on test plot L-1.

3.5 Data Collection

This section summarizes the major data collection components included in this experiment.

3.5.1 Photography

Super-8 movies and 35-mm still photography were used to permanently record test conditions and observations. Photographs were taken of each plot before, during, and after each oil application test as well as of significant textural and morphology changes that occurred on the beaches after the spill. The attempt to take time-lapse movies of the test plot changes failed because of equipment problems.

3.5.2 Sampling

Channel samples were taken from each test plot at various times following oil application and analyzed for total hydrocarbon content. Additional samples were taken from each test plot and analyzed by gas chromatograph and mass spectrophotometer (GC/MS) to determine the weathering characteristics of the paraffin, aromatic, and napthalene fractions of the oil. Table 3.2 shows the sampling schedule for the Phase I Shoreline Tests. The primary features of the sample collection programme were as follows:

(a) Total Hydrocarbons (see Section 6.0 for preliminary results)

- One 4-cm channel sample was taken from each plot before the spill to measure background oil content.
- After the spill, sample sets were taken from each test plot: one immediately after the spill and at 2, 4, 8, and 16 days after the spill.
- The post-spill samples were taken on each plot in 9 locations - 3 in each of the upper, middle, and lower sections of the plot.
- The samples consisted of a surface component and subsurface component (4-8 cm).
- The three samples from the upper, middle, and lower sections respectively were mixed to provide one composite surface and one composite subsurface sample of each of the three zones (see Fig. 3.5 for details).

(b) GC/MS

A single composite surface sample was taken from each test plot on day 1, 2, 4, 8, and 16 following oil application for GC/MS.

TABLE 3.2 Sample Collection Schedule (dots = total hydrocarbon samples; crosses = GC/MS samples)

TEST PLOT	BEFORE SPILL (Sf)		IMMEDIATELY AFTER SPILL (Sf)[1]	(Sb)[2]	1 DAY AFTER SPILL (GC)	2 DAYS AFTER SPILL (Sf)	(Sb)	(GC)	4 DAYS AFTER SPILL (Sf)	(Sb)	(GC)	8 DAYS AFTER SPILL (Sf)	(Sb)	(GC)	16 DAYS AFTER SPILL (Sf)	(Sb)	(GC)
		upper	●[3]	●		●	●	–	●	●	–	●	●	–	●	●	–
H-1	●	middle	*	●	x	●	*	x	*	●	x	*	*	x	*	*	x
		lower	*	●		●	*	–	*	●	–	*	*	–	*	*	–
		upper	●	●		●	●	–	●	●	–	●	–	–	●	●	–
H-2	●	middle	o	●	x	*	*	x	*	*	x	*	●	x	e	*	x
		lower	o	●		*	9	–	*	O	–	*	●	–	*	*	–
		upper	●	●		●	●	–	●	●	–	●	●	–	●	●	–
L-1	●	middle	*	o	x	*	●	x	S	*	x	*	●	x	*	●	x
		lower	*	o		*	●	–	*	*	–	*	●	–	9	●	–
		upper	●	●		●	●	–	●	●	–	●	●	–	●	●	–
L-2	●	middle	*	*	x	*	*	x	*	●	x	*	*	x	m	*	x
		lower	*	+		9	–	–	*	●	–	*	*	–	*	m	–
		upper	●	●		●	●	–	–	–	–	–	–	–	–	–	–
T-1	●	middle	*	*	x	*	*	x	*	*	x	●	*	x	●	*	x
		lower	*	*		*	O	–	–	–	–	–	–	–	–	–	–
		upper	●	●		●	●	–	–	–	–						
T-2	●	middle	●	●	x			x	●	●	x	●	●	x	●	●	x
		lower	●	●		*	*	–	–	–	–						
TE-1	●		●	●	x	* *	* *	x	●	●	x	●	●	x	●	●	x
TE-2	●		●	●	x	*	*	x	*	●	x	●	*	x	e	●	x

1 – Sf: Surface
2 – Sb: Subsurface
3 – ●: Composite sample comprised of 3 subsamples

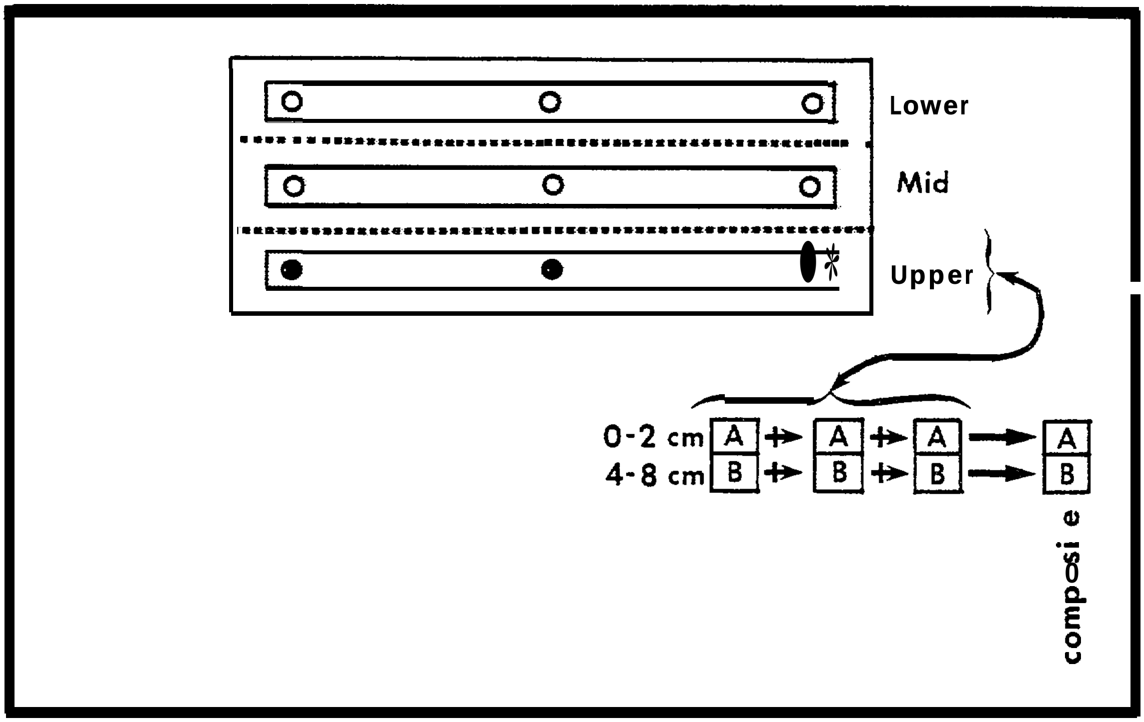

Figure 3.5 Schematic diagram of the sample collection methodology. Three subsamples were collected from each of the three intertidal zones (upper, middle, lower) and were combined to form composite surface samples (A) and composite subsurface samples (B).

3.5.3 Surveying

Elevation control and temporary bench marks were established on each of the test plots. On the high-energy beach where significant morphological changes occurred, the plots were resurveyed daily in order to establish the magnitude of the beach changes and the depth of burial of the oiled sediments.

3.5.4 Temperature Measurements

The ground temperature measurements, which were made to evaluate the effects of oil on the subsurface thermal regime, were made daily throughout the study and are discussed in detail in Section 8.0.

3.6 Test Schedule

The actual dates of oiling the plots are given in Table 3.3 and occurred during open-water season with mean daily air temperatures well above freezing. In general, the actual oiling operations encountered no major logistical problems and the spill application was completed within the allocated time.

TABLE 3.3 Oil Application Schedule

TEST PLOT #	DATE OF OIL APPLICATION	TIME (EDT)	MEAN AIR TEMPERATURE
H-1	23 August 1980	1400	3.5°C
H-2	23 August 1980	1600	3.5*C
L-1	21 August 1980	1400	3.8°C
L-2	22 August 1980	1400	2.5°C
T-1	20 August 1980	1000	3.0°C
T-2	20 August 1980	1400	3.0°C
TE- 1	23 August 1980	1500	3.5°C
TE-2	23 August 1980	1800	3.5°C

The Cape Hatt region and coastline is typical of much of the Canadian Arctic Archipelago in that coastal relief is high (>500 m within a few kilometres of the coast), offshore areas are deep, elongate channels, and much of the beach sediment is coarse pebble-cobble sized material. Like other areas in the Arctic the open-water season is short, 2 to 3 months, which severely limits the amount of wave energy that may be expended on an annual basis. The presence of sea ice not only limits wave activity but also constantly scours and mixes sediments near the shoreline and may ultimately be found to be an important mechanism for redistributing oil in the Arctic.

Four locations were selected in the Cape Hatt region as test sites for the controlled oil spills. The four sites differed in terms of geomorphology and wave exposure levels and were selected on the basis of their representativity to larger sections of coastline and on the basis of their logistical accessibility. A brief description of each of the four sites is given in terms of geomorphic, sedimentologic, and process characteristics. A summary table of these major site characteristics is also included (Table 4.1).

4.1 Control Plot Descriptions

Four separate control plots at two different sites (Fig. 3.1) were established on raised beaches similar in sediment characteristics to the two intertidal sites. The plots are not currently affected by wave and tide action and provide a comparison of oil weathering properties not directly affected by active marine processes.

The main control plots (T-1, aged oil and T-2, emulsified oil) were located on “Crude Oil Point” in Z-Lagoon (Fig. 3.1). The raised beach (Fig. 4.1) on which the plots were located consisted of a gravelly sand

TABLE 4.1 Spill Site Characteristics

TEST PLOT #	SEDIMENT TEXTURE	BEACH SLOPE	MAXIMUM FETCH DISTANCE AND DIRECTION
H-1, H-2	Gravelly Sandy Pebble	10°	90 km (ENE)
L-1	Sandy Pebble	9°	1.5 lull (w)
L-2	Cobbly Pebbly Silty Sand	7°	1.5 km (w)
T-1, T-2	Sandy Pebble	“5°	Control Plot (unaffected by waves)
TE-1, TE-2	Cobbly Pebbly Sand	<5°	Control Plot (unaffected by waves)

substrate covered by a thin shingle lag deposit (Fig. 4.2). The plots sloped slightly (<5°) towards the shore with the seaward edge approximately 0.5 m above MHWL (mean high-water level). The depth to the ice-bonded surface was 0.8 m at the time of oiling with a perched groundwater table at approximately 0.7 m. Included in the test plot were several small clumps of moss and stunted willows, suggesting the plots have not been recently submerged. Figure 4.3 schematically illustrates the plot layout and Figure 4.4 shows a photograph immediately after the oiling operation.

The control plots were instrumented at the time of oiling in order to document changes in the thermal characteristics of the oiled and non-oiled substrate. Net radiation and subsurface ground temperatures were recorded at the aged oil plot (T-1) and at an adjacent unoiled plot (Fig. 4.3). Details of the measurements and preliminary results are included in Section 8.0.

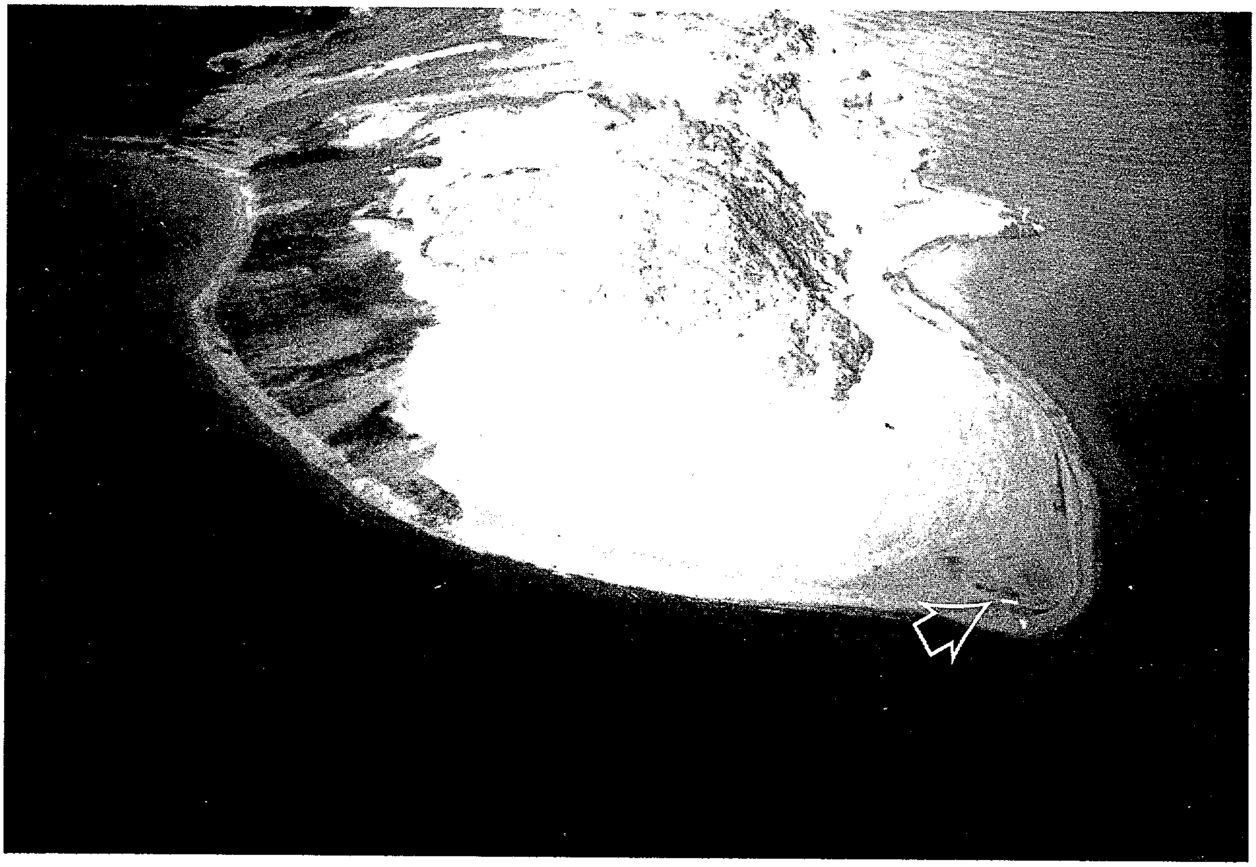

Figure 4.1 Oblique aerial photograph of “Crude Oil Point” in Z-Lagoon showing the location of the experimental control plots, T-1 and T-2.

Two other control plots (TE-1, aged oil; TE-2, emulsified oil) were established in the backshore area of the high-energy intertidal plot location (Fig. 3.1) for microbiology background studies. The substrate in this location is a cobbly sand material and slopes gently (<5°) seaward (Fig. 4.5). The plots were located approximately 1 m above the MHWL. No other specialized instrumentation was installed on these plots, although detailed microbiological measurements were made following the spill.

Both total hydrocarbon samples and GC/MS samples were collected from each of the control plots according to the sampling schedule listed in Table 3.2.

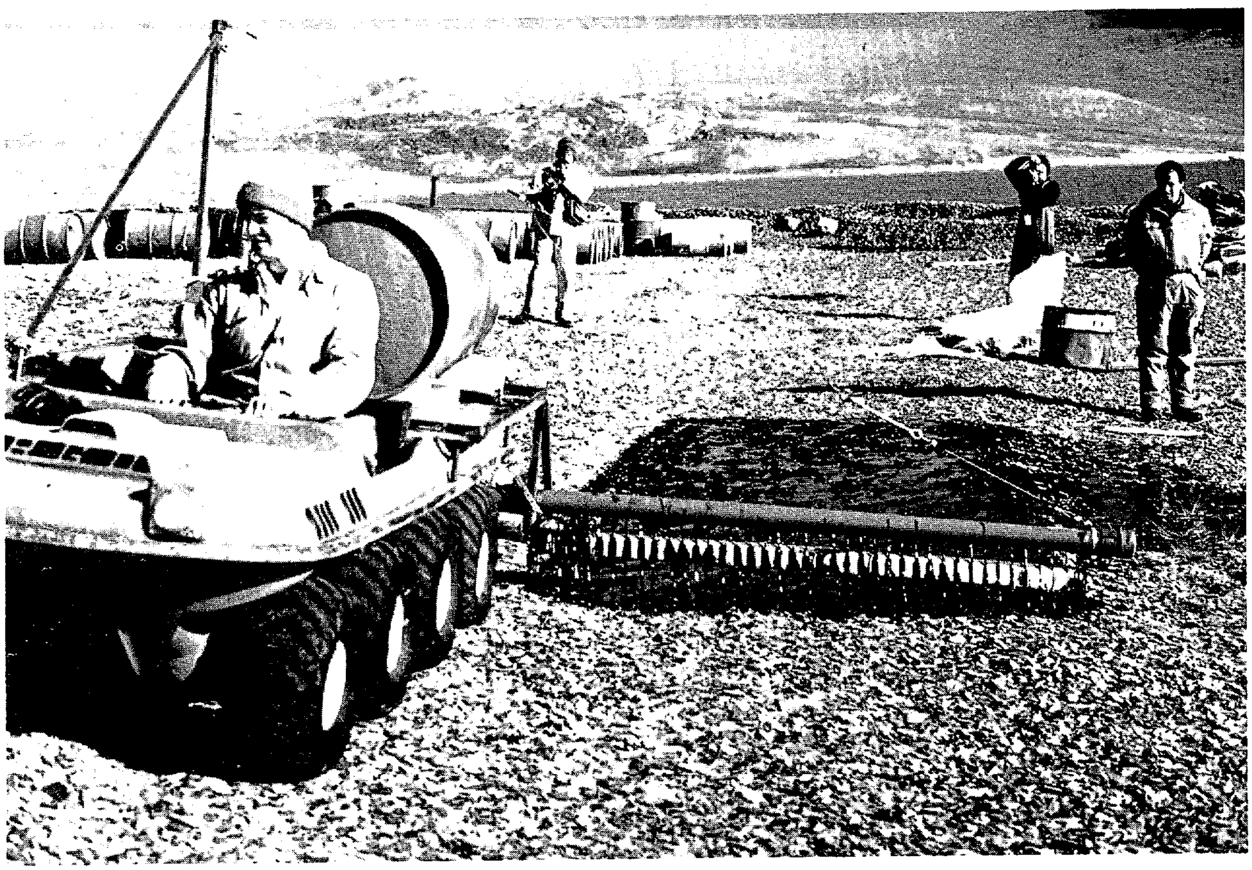

Figure 4.2 Photograph of the T-1 test plot during the oiling operation. Note the “shingle-type” sediment cover as well as the low beach slope from left to right.

4.2 Intertidal Plot Descriptions

Intertidal test plots were established at two locations to monitor the effects of ice, tidal and wave action on the spilled oil. The locations were selected on the basis of variations in wave-energy levels between the sites (Table 4.1).

Two of the plots (H-1, aged oil; H-2, emulsified oil) were established in a high wave-energy pocket beach environment (Fig. 3.1, Bay #102) on the east coast of Cape Hatt.

The beaches on this section of coast are exposed to the relatively open water of Eclipse Sound where wave fetch distances exceed 90 km.

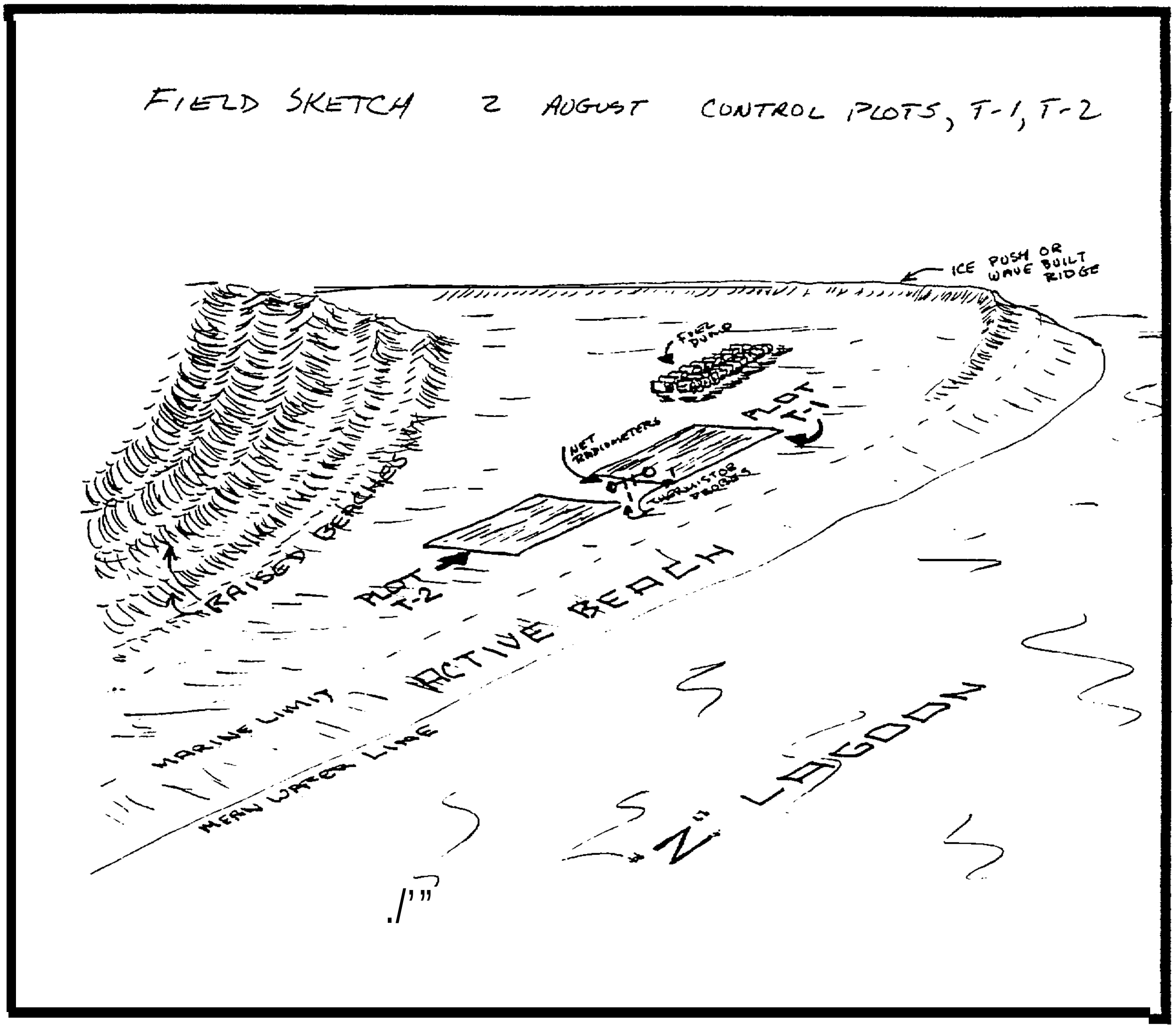

Figure 4.3 Field sketch of the control plot location showing the general morphology around the plots as well as the location of the instrumentation on the plot.

Figure 4.4 Photograph of the two control plots immediately after oiling. Plot T-1 is to the left and plot T-2 is to the right.

Figure 4.5 Photograph of test plot TE-2 located in the backshore area of Bay #102 (see Fig. 3.1 for location).

During the study period, wave heights in excess of 1 m were observed, making this a relatively high-wave energy environment in terms of the Arctic. The open exposure of this section of coast is also expected to result in relatively active scouring by sea ice movement against the shore. The general topography surrounding the test site is illustrated in the oblique aerial photograph (Fig. 4.6), which shows the pocket beach and open waters of Eclipse Sound.

Morphologic characteristics of the pocket beach system appeared representative of exposed beaches on this coast and included: (i) a relatively steep sandy beach face, (ii) a coarse gravelly pebble berm,

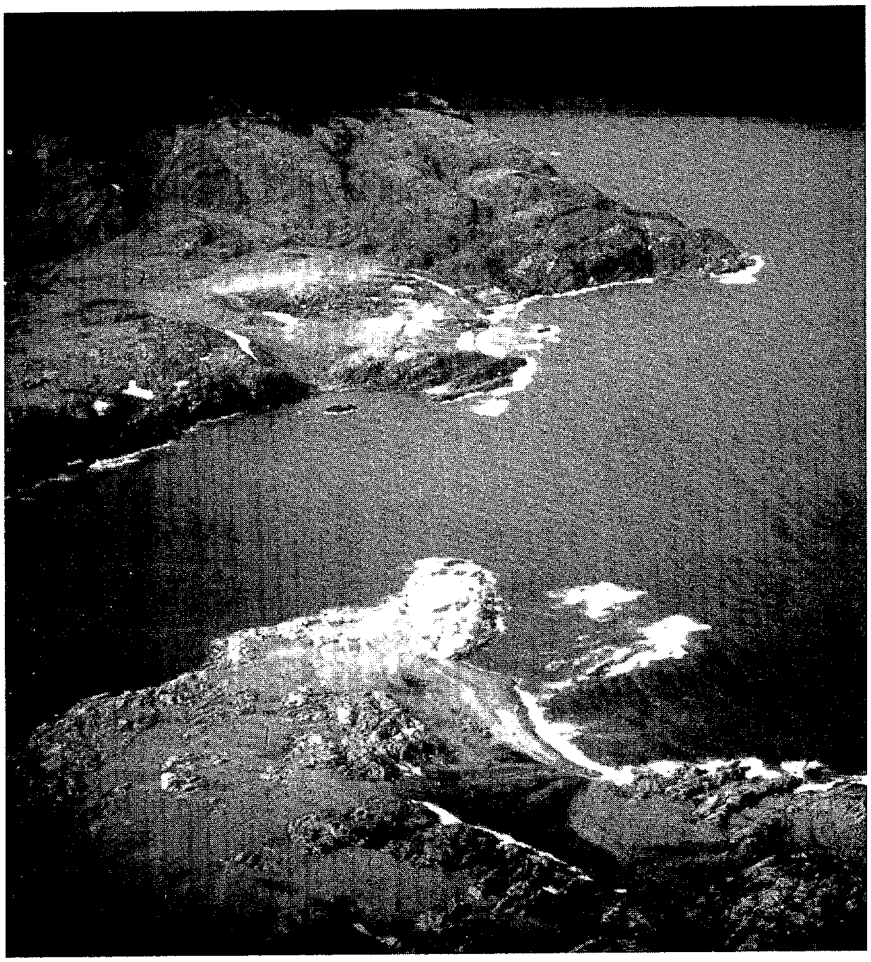

Figure 4.6 Oblique aerial photograph of Bay #102 (lower right) where the high energy test plots were located.

(iii) a gently sloping, gravelly sand backshore that lies above the MHW line but is occasionally inundated by storm surges, and (iv) a boulder-cobble fringe that separates the marine pocket beach sediments from the terrestrial sediments (Figs. 4.7 and 4.8).

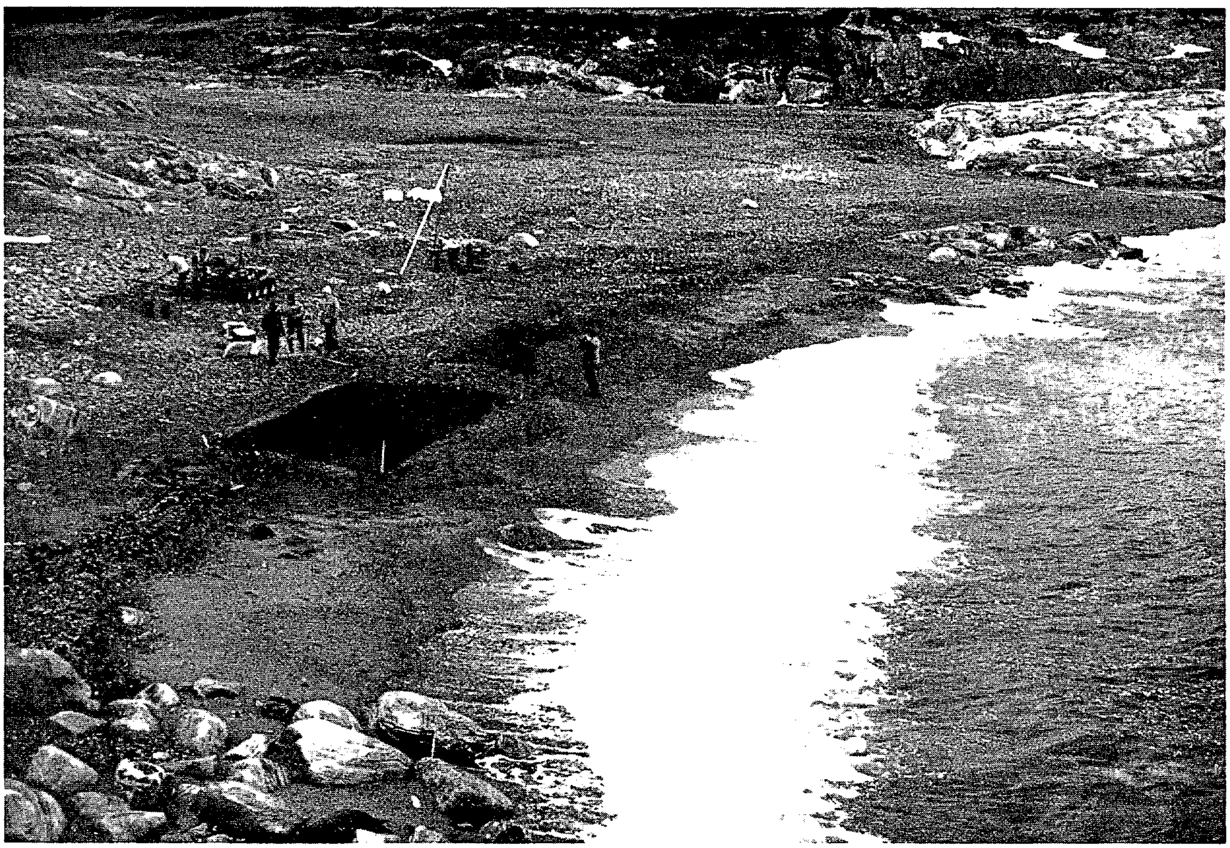

Figure 4.7 Photograph of the high-energy test plots, H-1 and H-2, immediately after oiling. Plot H-1 is in the middle of the photo and plot H-2 is in the foreground. The backshore control plots, TE-1 and TE-2, were located to the left on the photo in the vicinity of the ATV.

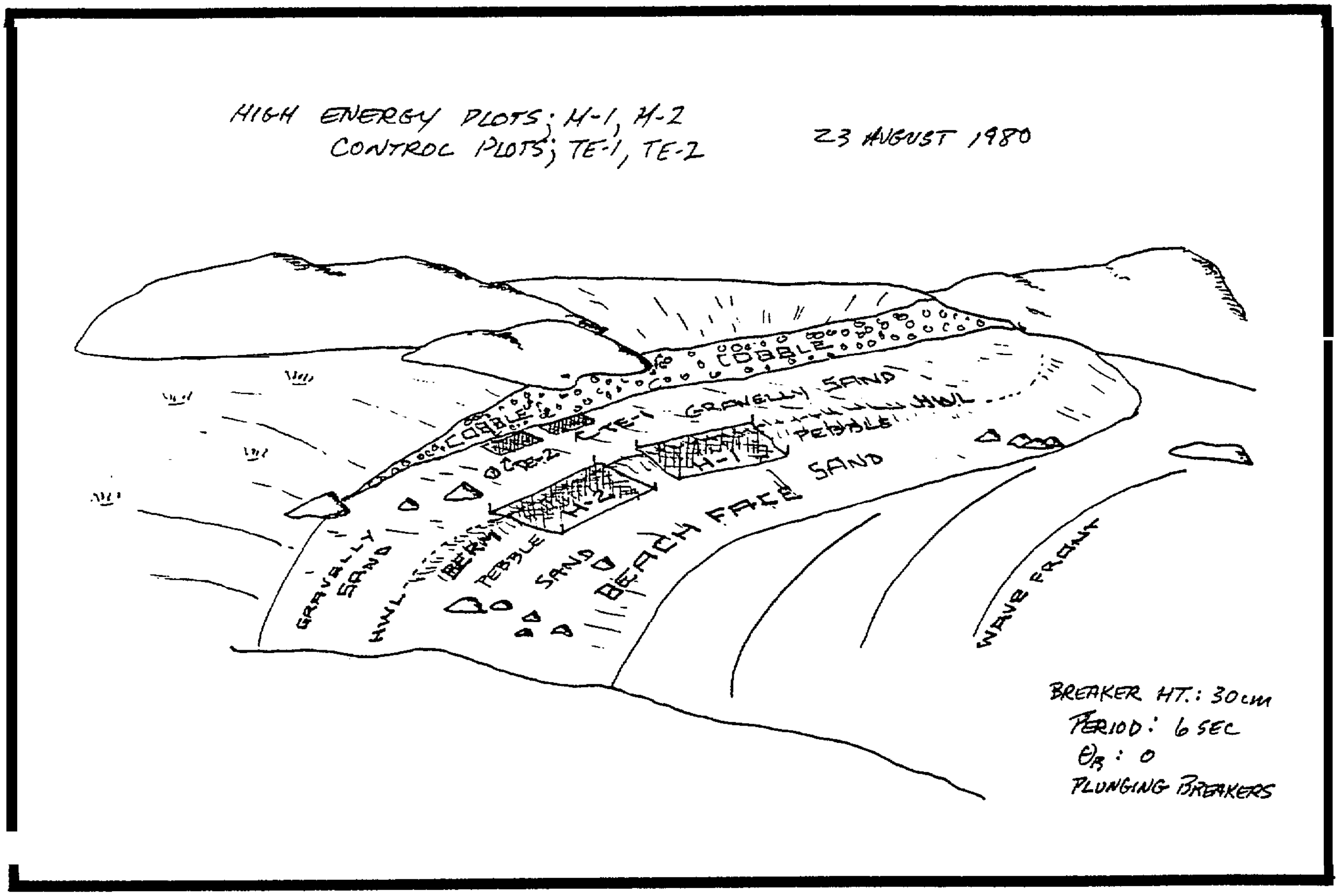

Figure 4.8 Field sketches of the high-energy test plots, H-1 and H-2, illustrating the significant beach morphology of this test site.

A plan view diagram of the experimental setup is shown in Figure 4.9 and beach profiles, which were surveyed at each end of each plot, are illustrated in Figure 4.10. The profiles show that the maximum intertidal slopes occurred on the beach face immediately seaward of the small gravel-pebble berm.

The low-energy spill site was established along the shoreline of Bay #103 in Z-Lagoon (Fig. 3.1) and was considered representative of much of the Z-Lagoon shoreline in that: (1) wave-energy levels along the shore are relatively low, (2) the intertidal zone is narrow (<15 m), (3) beach sediments ranged from clay to boulder-sized material, (4) the beach was "soft" with a high groundwater table, and (5) the tundra-covered backshore

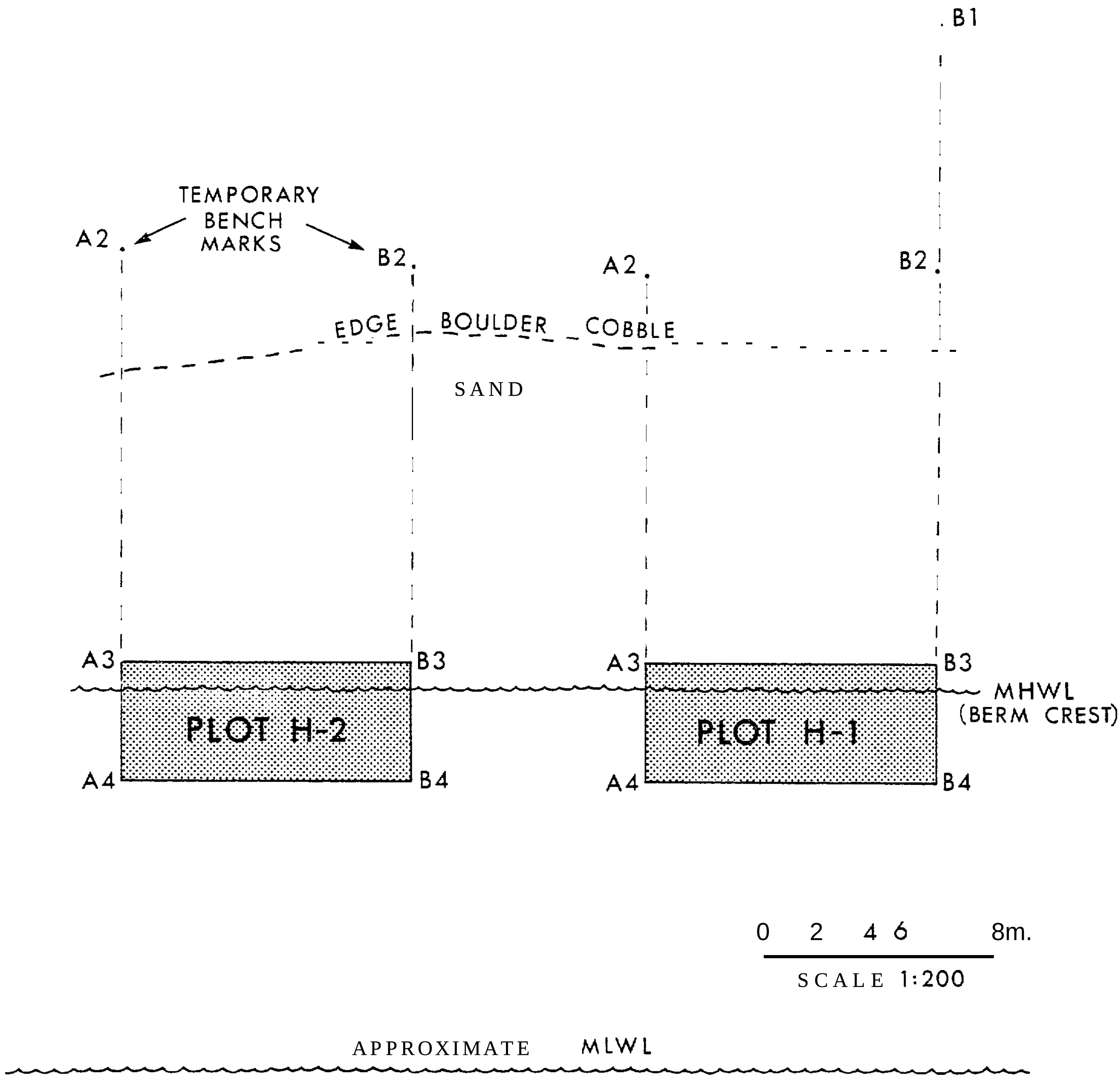

Figure 4.9 Plan view diagram of the high-energy test site showing plots, H-1 and H-2.

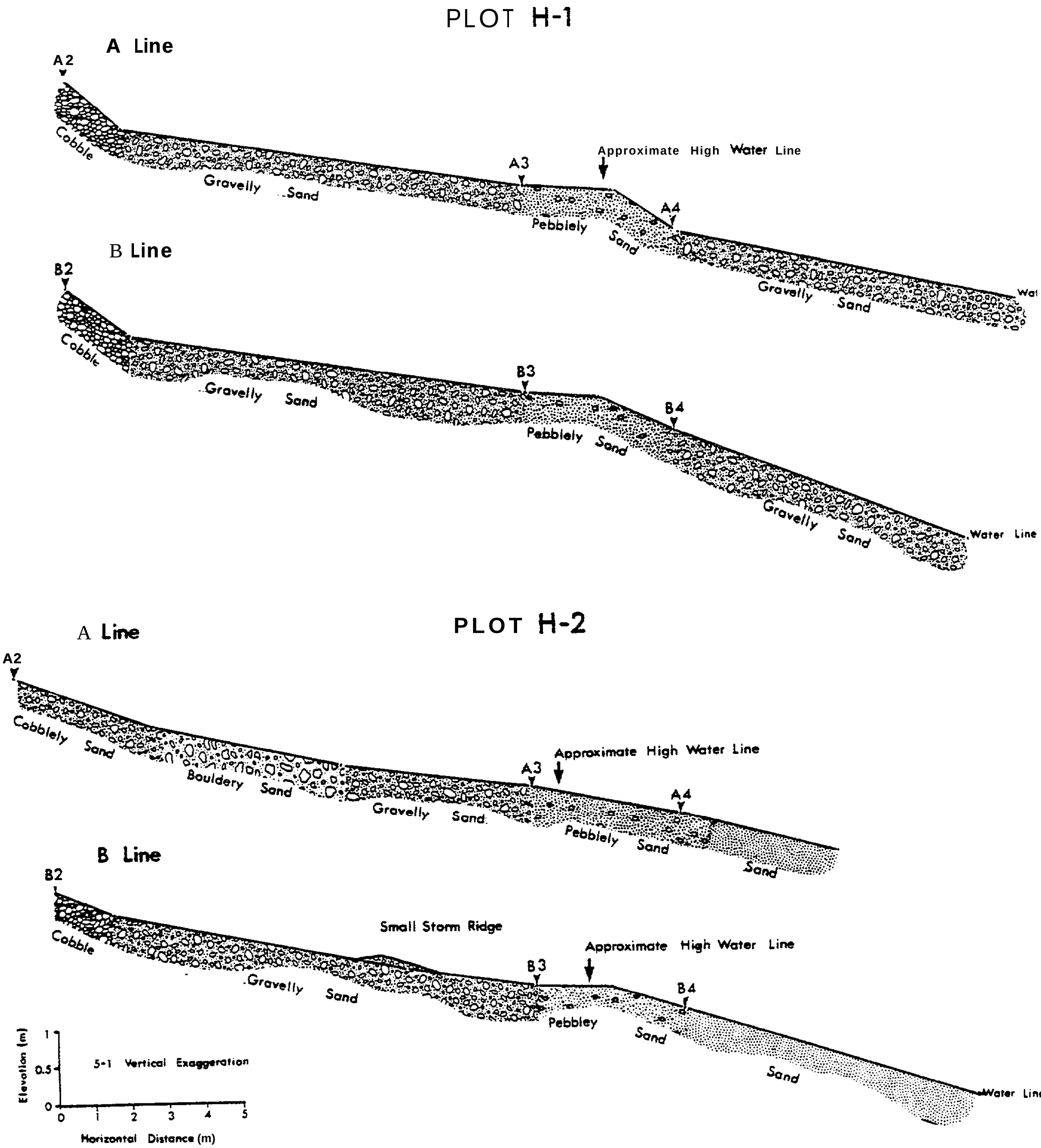

Figure 4.10 Beach profiles from the high-energy test site; (a) from H-1, and (b) H-2.

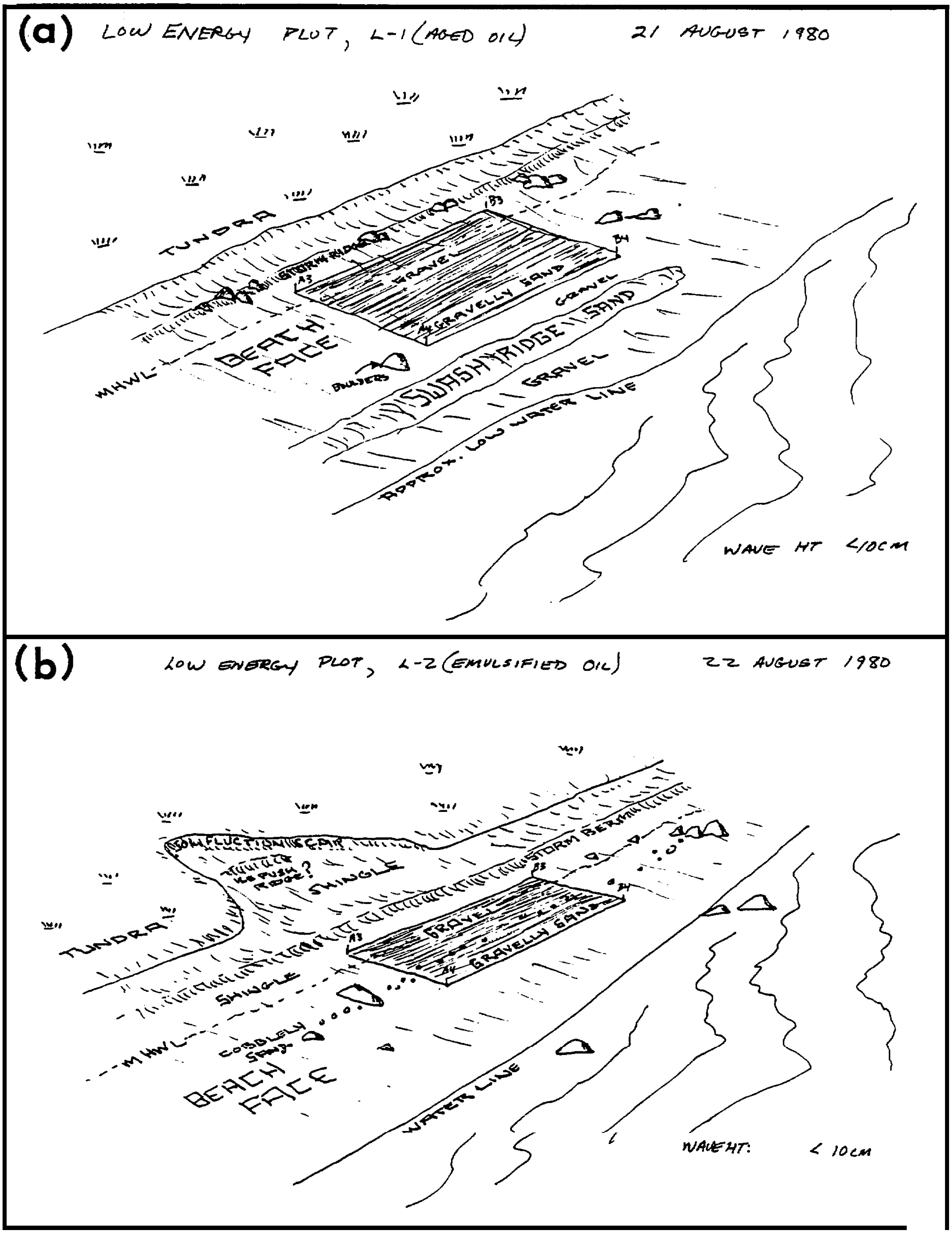

Figure 4.11 Field sketches of plots (a) L-1 and (b) L-2.

areas were dominated by solifluction processes. The basic features of the two low-energy test sites (L-1, aged oil; L-2, emulsified oil) are shown in the field sketches (Fig. 4.11a and b).

Plan view diagrams of the experimental setup are included in Figure 4.12, and the beach profiles, which were surveyed at the end of each plot (i.e., two profiles per plot) show the cross-sectional form of the backshore and intertidal morphology (Fig. 4.13).

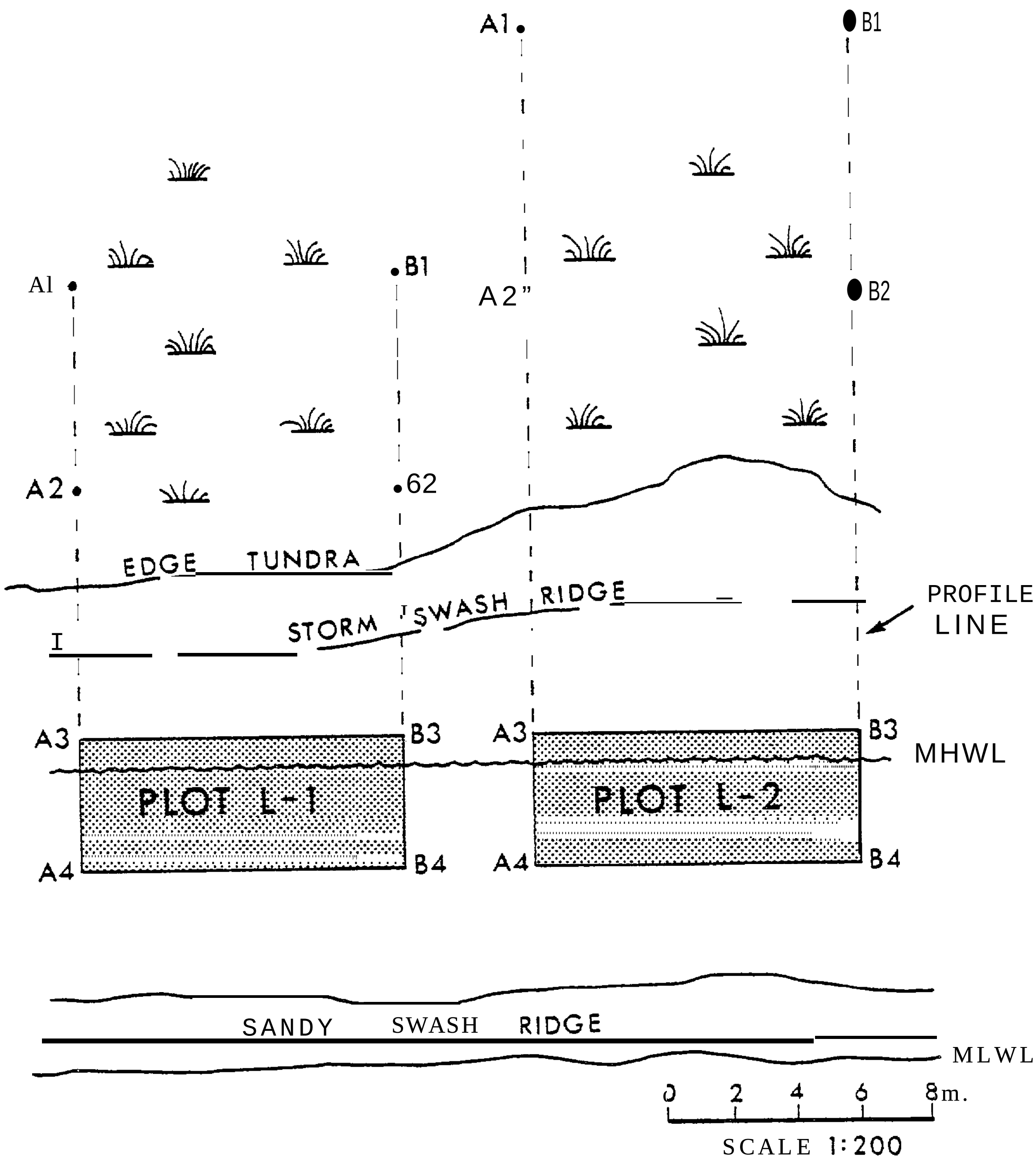

Figure 4.12 Plan view diagrams of test plots L-1, and L-2.

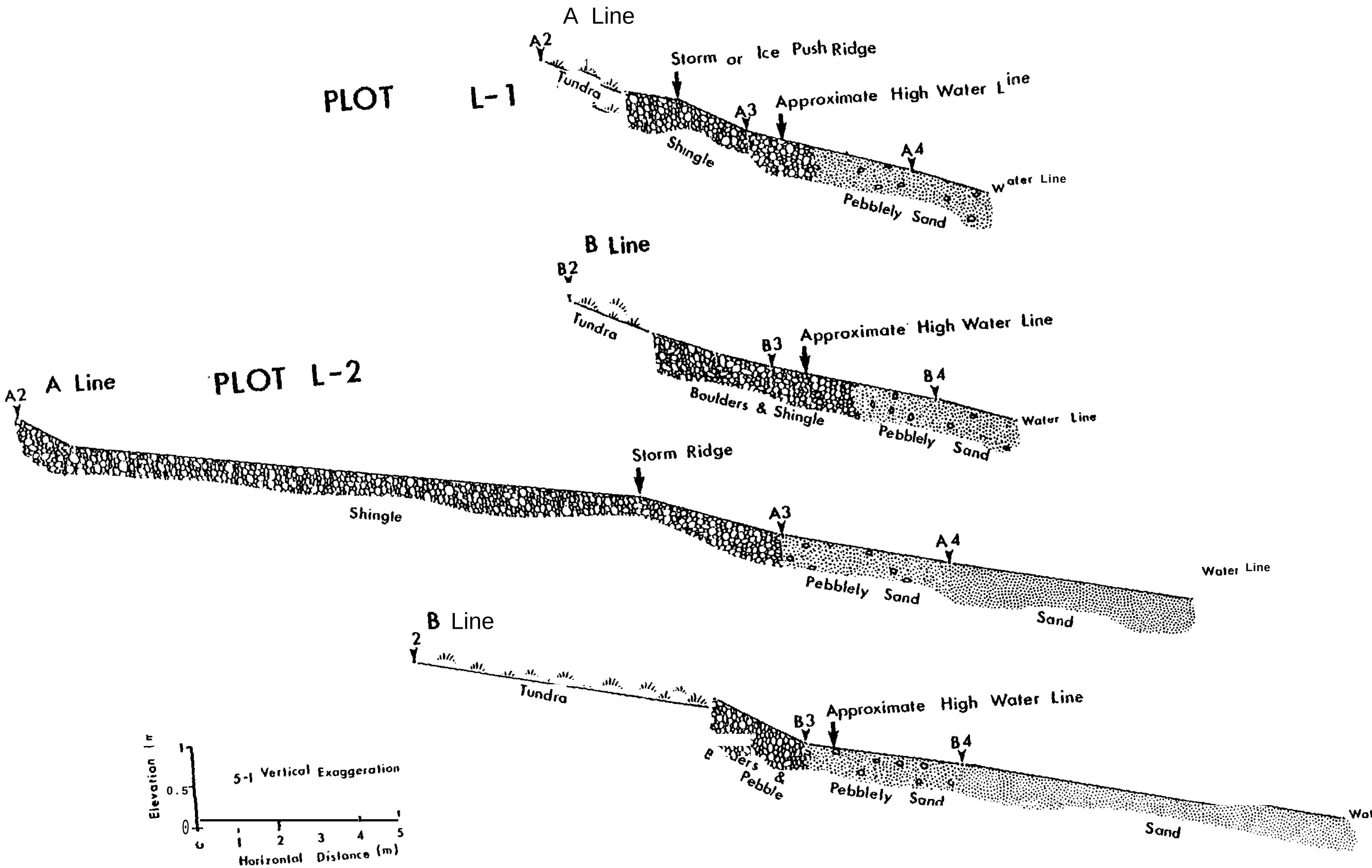

Figure 4.13 Beach profiles from the low-energy test site: **(a)** L-1 and (b) L-2.

5.0 OILING TECHNIQUES

The various techniques used in the preparation of the oil-water emulsification and in the application of the oil to the beaches are described in this section. The application technique eventually used was flexible and performed well during the tests. Alternative application techniques of varying sophistication were also considered in case of logistical problems in the field, however, the preferred technique proved adequate and the alternatives were not used.

5.1 Oil-Water Emulsification System

Six drums of Lago Medio crude oil and six drums of seawater were used to manufacture twelve drums of a (50% water-50% oil) water-in-aged crude oil emulsion. The system used to make the emulsion is shown in Figure 5.1. One barrel of crude oil and one barrel of seawater were connected via 7.6-cm (3-inch) diameter hoses to a "T" connection. The oil and water flowed by gravity through the "T" connection and through another 7.6-cm (3-inch) diameter hose into a 1.8-m (6-foot) square fiberglass mixing tank. The oil/water mixture was then drawn off via a bottom drain and pumped through a 5-cm (2-inch) centrifugal pump back into the mixing tank. The pumping continued until an emulsion was formed (in most cases, this required only five minutes of pumping). The point at which an emulsion was formed was very obvious and was characterized by a shift in colour from black to brownish-black and a sudden increase in the viscosity of the mixture. The entire process, including setting up the system, making 12 drums of emulsion, and cleaning up the equipment, was accomplished in six hours with a four to five man crew.

5.2 Oil Application Techniques

In this experiment, a small, self-contained all-terrain vehicle (ATV) was used to apply the oil onto the test plots. The application system

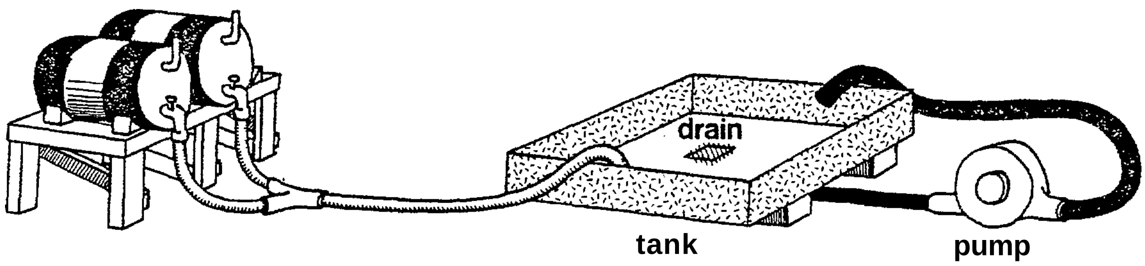

Figure 5.1 Schematic diagram of the oil-water emulsification system.

proved to be flexible and performed well despite varying beach slope and sediment conditions.

The basic configuration of the application system is schematically illustrated in Figure 5.2 and shown in photos of the actual oiling operation (Figs. 5.3 and 5.4). The main components of the system consisted of: (1) an eight-wheeled, ARGO amphibious ATV, (2) a 45-gallon oil drum *secured to* the back of the ATV, (3) a gasoline-powered, centrifugal pump to transfer the oil from, the drum to the distributor pipe under pressure, and (4) *a* 2-m long distributor pipe which discharged the oil through 0.64-cm (%-inch) holes drilled at 5.1-cm (2-inch) centres. A small tin distributor plate was attached to the distributor pipe (see Fig. 5.5) to promote sheeting of the oil and to provide a more uniform oil distribution.

At the test site, oil was transferred to the ATV-mounted drum by hoisting the supply drum with an A-frame (Fig. 5.6), connecting the two drums with a hose, and filling the ATV drum by gravity feed. The ATV *was* then positioned to pass over the lower 2 m of the 4 x 10 m test plots.

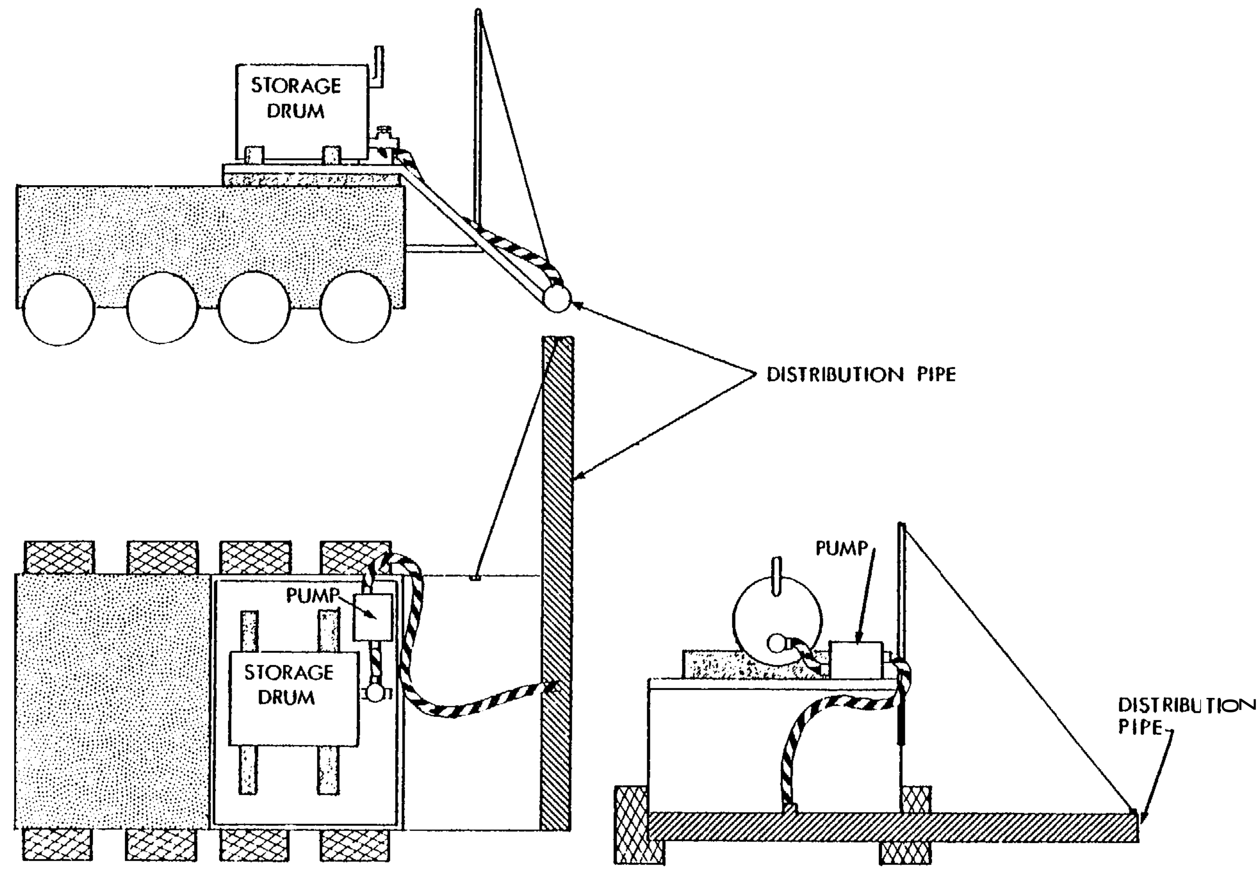

Figure 5.2 Schematic diagram of the oil application system.

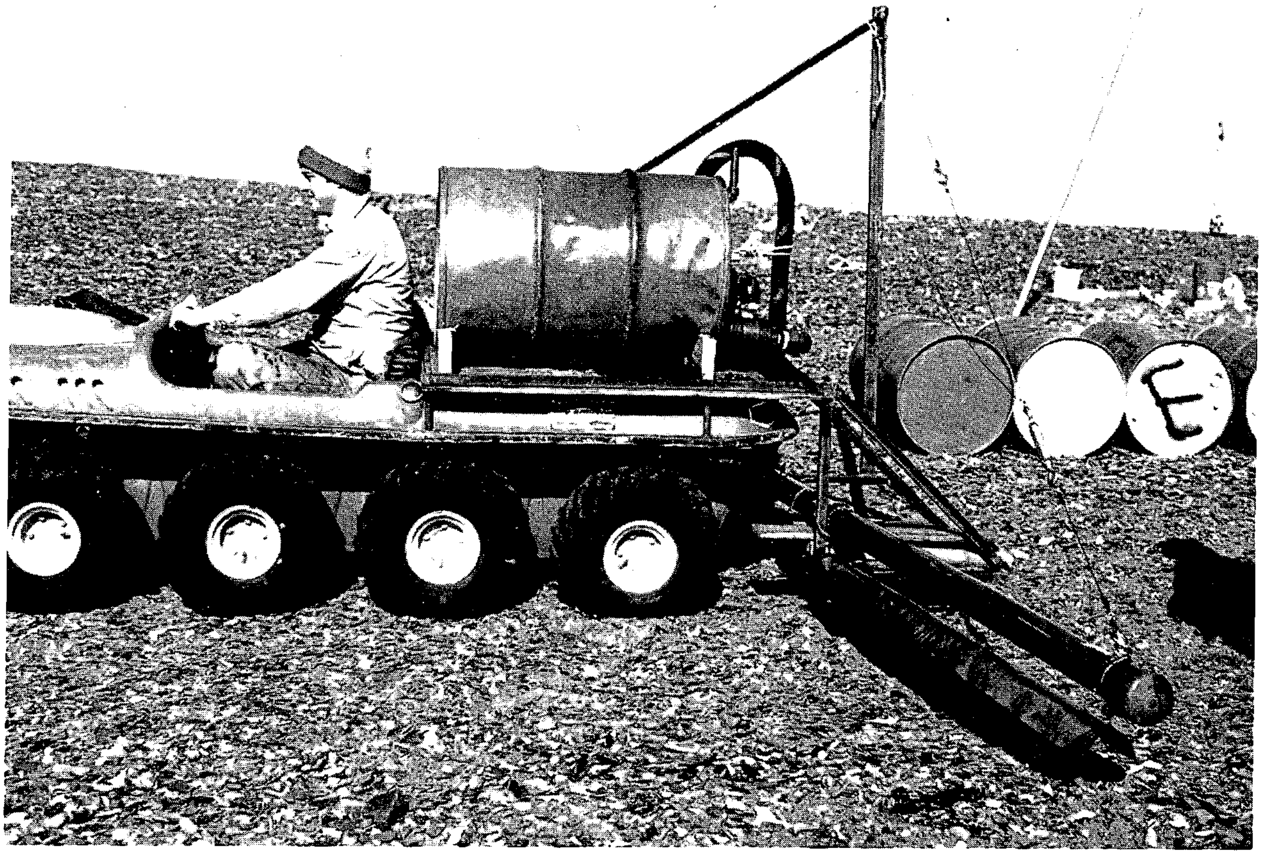

Figure 5.3 Photograph of the oil application system showing the ATV, the storage drum on the back of the ATV, and the distributor pipe behind the ATV.

Because the slope of the beach varied from plot to plot, the distributor bar was adjusted to the horizontal position immediately prior to the oil-ing to ensure an even flow of oil. The oil pump was started and as the oil reached the distributor plate, the ATV driver advanced across the test plot at a predetermined speed (Table 5.1). The speed was determined by the calibrated flow rate (3.1 1/s; 40 Imp. gal/rein) necessary to cover the plot with a l-cm thickness of oil. In practice, a single pass took between 60 and 90 seconds, depending on the viscosity of the oil at the time of application. Because the emulsified oil was comprised of 50 per-cent water, two passes over the same 2-m swath were required to apply the same amount of oil (i.e., four passes were required for the entire 4 x 10 m plot.

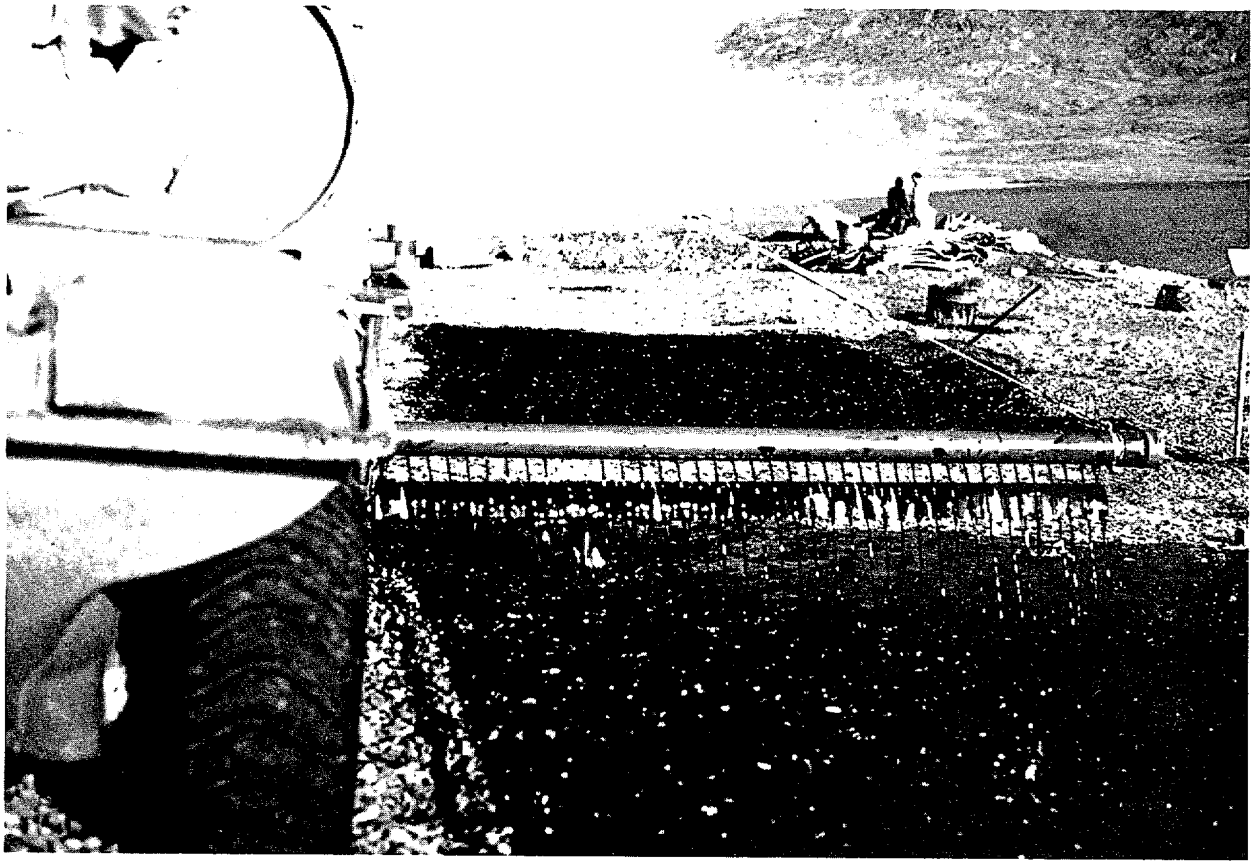

Figure 5.4 Photograph of the oiling operation at plot T-2 showing the second application of emulsified oil to the plot.

Operational difficulties that were encountered during the application procedure included: (a) difficulty maintaining a slow but uniform speed with the ATV, (b) changes of the beach slope within the plot, which caused tilting of the distributor pipe and non-uniform oil application, (c) disturbance of the plots by the ATV wheels, which in some places created depressions conducive to pooling of the oil, and (d) excessive runoff of oil from the plot. In general, the problems were considered minor and at the worst resulted in a slightly non-uniform distribution of oil over the plot. In order to minimize clean-up operations, the problem of excessive runoff was countered by digging a trench at the base of the plot, lining it with polyethylene plastic, and removing the oil as it collected (see Fig. 3.3). This procedure also permitted an accurate estimate of runoff as the amount removed from the trench was noted.

Figure 5.5 Photograph of the distributor pipe with attached oil distribution plate, which causes a sheeting of the oil and generally promotes a more uniform distribution of the oil on the plots.

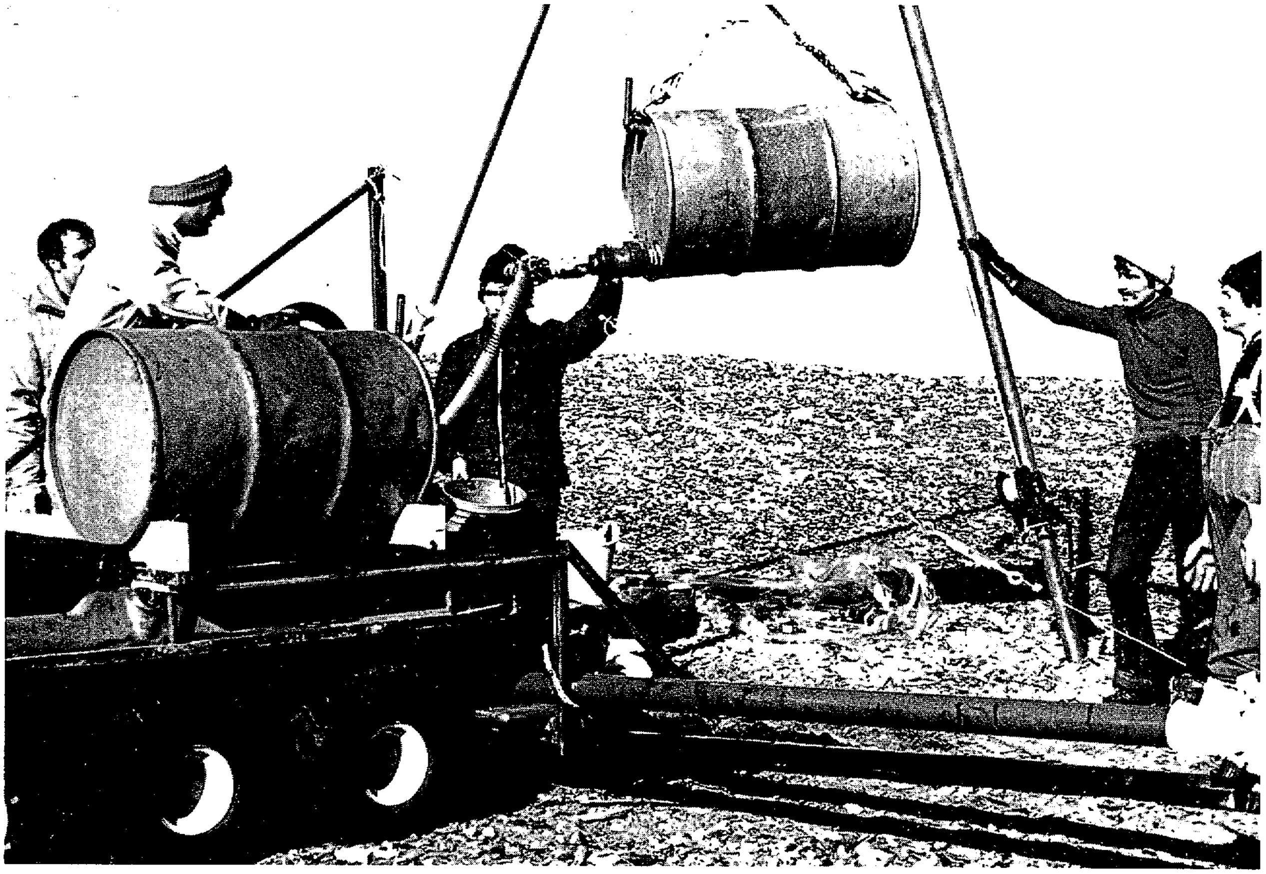

Figure 5.6 Refilling of the ATV-mounted oil storage drum at the test site.

TABLE 5.1 Oil Application Parameters

Application System:	modified, 8-wheel ATV with self-contained storage drum, pump, and distribution pipe
Capacity:	0.208 m^3 or 208 1 (45 Imp. gallons)
Pumping Rate:*	2.3-3.1 1/s (30-40 Imp. gal/rein)
Distribution Swath:	2 m
Application Rates:*	8-10 m/min or 2.3-3.1 1/s (30-40 Imp. gal/rein)

*partially dependent on oil viscosity at the time of the spill

5.3 Oil Application to the Test Plots

The same basic oil application system described above was used on each of the test plots, however, because of variations in beach slope, texture, and groundwater elevation, the retention of oil on each beach varied considerably. A brief summary of amounts of oil applied and retained at each site is given in Table 5.2.

TABLE 5.2 Oil Application and Retention Amounts

TEST PLOT	AMOUNT APPLIED* M^3 (IMP GAL)	AMOUNT RETAINED* M^3 (IMP GAL)	% OIL RETAINED
H-1 (aged oil)	0.41 (90)	0.36 (80)	89
H-2 (emulsified oil)	0.41 (90)	0.36 (80)	89
L-1 (aged oil)	0.41 (90)	0.25 (56)	62
L-2 (emulsified oil)	0.20 (45)	0.08 (17)	38
T-1 (aged oil)	0.41 (90)	0.33 (72)	80
T-2 (emulsified oil)	0.41 (90)	0.34 (75)	83
TE-1 (aged oil)	0.05 (10) approx.	?	?
TE-2 (emulsified oil)	0.05 (10) approx.	?	?

*numbers refer to the amount of oil, i.e., numbers for the emulsified plots should be doubled to give the total amount of water and oil emulsification applied (e.g., 17 gal of oil equals 34 gals of oil-water emulsification)

In general, the amount of oil retained was within 80 percent of the design amount. Special problems were encountered on the low-energy test plots because these beaches were relatively steep, had high silt contents and high groundwater tables. These characteristics were accentuated on plot L-2 (low-energy, emulsified) *as* Figure 5.7 illustrates. On the L-2 plot, only half the normal amount of oil (0.2 m^3) was applied because of the excessive runoff. It was felt that the beach surface had reached its saturation level and the additional application of oil would not have re-suited in any additional retention.

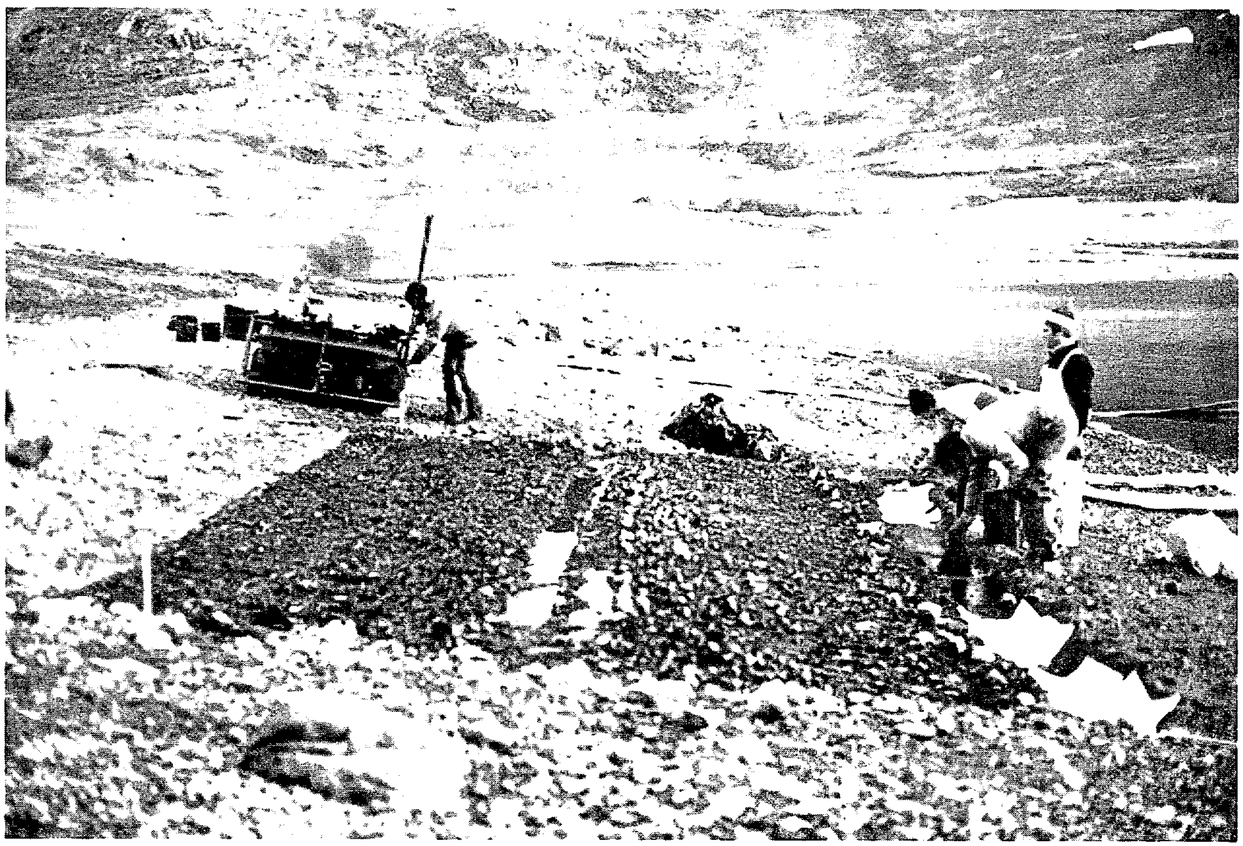

Figure 5.7 Photograph of the L-2 plot (emulsified oil) immediately after the oiling operation. Note the tire tracks left in the soft beach by the all-terrain vehicle as well as the pools of oil that collected in the tire tracks.

6.0 TOTAL AND COMPOSITIONAL HYDROCARBON CHANGES

Two sets of samples were collected from each of the oiled plots in order to determine the weathering and dispersal characteristics of the oil. The first sample set was used for determining the total amount of hydrocarbons trapped in the sediment. Analysis of the initial hydrocarbon content of the sediments immediately after the spill gave an estimate of the oil retention characteristics of the various sedimentary environments that were oiled and the change of total hydrocarbon content in time provides an index of the effectiveness of natural processes (e.g., tide and wave action) in removing and dispersing the oil.

The second sample set was used for determining the compositional changes of the spilled oil. By comparing the compositional changes of the control plot samples, which were not affected by marine processes, with those of the intertidal plot samples an estimate of atmospheric versus marine-related weathering rates can be made. Analysis of compositional change over a several year period also provides an index of the long-term microbial decomposition effects in an arctic environment.

6.1 Sampling Techniques and Analytical Techniques

It was originally anticipated that the hydrocarbon samples could be collected using a small coring tube; however, the coarseness of the beach material and concern over sample contamination prevented the use of such a technique. The sampling technique that was eventually used consisted of collecting samples, both surface and subsurface, with a small trowel. As mentioned in Section 3.0, the final sample was a composite sample comprised of three to nine subsamples (see Table 3.2), which were placed in hydrocarbon-cleaned glass bottles and returned to the laboratory for analysis. The subsurface samples were collected from a 4- to 8-cm depth.

The total hydrocarbon analysis provided a measure of the present hydrocarbon content (by weight) of the sediment samples; amounts of hydrocarbon in the sediments were determined by gravimetric and infrared (IR) methods (see Green, 1981, for further information on the total hydrocarbon analyses).

Compositional information on the total hydrocarbons analyzed was determined by gas chromatography and mass-spectrophotometer (GC/MS) analyses (see Boehm, 1981 for additional information on the compositional hydrocarbon analyses).

6.2 Total Hydrocarbon Change

Results of the total hydrocarbon analyses are included in Table 6.1 for each plot (see Fig. 3.1 for plot locations and characteristics). The estimates are useful for illustrating the gross changes in sediment hydrocarbon contents immediately after the spill and, in general, support the observations that were made in the field.

Analysis of the total hydrocarbon contents indicates the following trends:

(i) Initial sediment oil contents were between one and four percent with the emulsified oil plots generally showing lower oil retention values than the aged oil plots (Table 6.2).

(ii) The range of individual sample oil content indicates that the distribution of oil on the plot was not completely uniform (Tables 6.1 and 6.2).

(iii) The values of the lower energy, emulsified oil plot (L-2) showed the lowest amounts of hydrocarbons, indicating that oil retention was least on this plot (Table 6.2).

(iv) Subsurface oil contents were initially lower than surface values in most plots (Table 6.1), however, this trend reversed during the experiment such that subsurface oil contents were generally greater than or equal to the surface values after the first day. The trend was less distinct in the control plots, which were not exposed to marine processes.

TABLE 6.1 Total Hydrocarbon Analyses

		HIGU WAVE ACTION				LOW WAVE ACTION				BACKSHORE PLOT (Z LAGOON)				BACKSWORE PLOT (ECLIPSE SOUND)			
		AGED (H-1)		EMULSIFIED (U-2)		AGED (L-1)		EMULS IF I ED (L-2)		AGED (T-1)		EMULSIFIED (T-2)		AGED (TE-1)		EMULS IF IED (TE-2)	
		% OIL IN SEDIMENT				% OIL IN SEDIMENT				% OIL INSEDIMENT				% OIL IN SEDIMENT			
		rface	Sub-Surface	Surface	Sub-surface	Surface	Sib-Surf ace	Surface	Sub-Surf ace	Surface	Sub-Surf ace	Surface	Sub-Surface	Surface	Sub-Surface	Solace	Sub-Surfac
IMEDIATELY)LLOWING :ST	UPPER	2.04	1.04	1.59	2.80	0.67	0.88	0.19	0.05	2.24	1.65	0.94	0.91				
	MIDDL	1.16	1.49	0.19	0.13	0.87	1.30	0.45	0.22	5.37	1.88	1.27	0.95	4.62	2.94	5.10	0.17
	LOW EF	'.74	1.16	2.32	0.22	3.6o	2.46	0.37	no sample	4.43	3.43	1.73	2.75				
DAYS F1ER :ST	UPPER	).001	0.0561	0.001	0.002	0.46	0.80	0.021	0.011	5.17	1.68	2.82	1.08				
	MIDDL	).019	0.88	0.002	0.001	0.47	0.09	0.032	0.006	3.79	1.70	1.20	2,31	4.96	1.52	10.2	0.46
	LOWEF	).001	0.055:	0.001	0.001	0.61	0.69	0.014	0.005	8.53	5.62	1.90	4.74				
DAYS 1'TER ESI	UPPER	).007	0.18	0.010	0.11	0.45	0.77	0.008	0.002								
	MIDDL	).005	1.62	0.001	0.003	0.25	0.94	0.034	0.001	3.38	3.50	1.27	1.33	5.42	3.27	2.89	6.15
	LOW EI	).016	0.22	0.001	0.001	0.47	0.47	0.006	0.001								
DAYS FTER EST	UPPER	).037	2.74	0.005	no sample	0.57	1.26	0.037	0.002								
	MIDDL	).32	0.0101	0.0003	0.0004	0.77	1.83	0.001	0.016	6.58	1.71	6.00	5.81	4.04	4.77	5.80	0.050
	LOWEI	).001	0.26	0.0009	0.0001	0.60	1.08	0.001	0.005								

TABLE 6.2 Initial Mean Hydrocarbon Content*
(surface and subsurface)

TEST PLOT	OIL IN SEDIMENT (%)	RANGE (%)	NUMBER OF SAMPLE S
H-1	2.44	1.04-7.74	6
H-2	1.21	0.13-2.80	6
L-1	1.63	0.67-3.60	6
L-2	0.24	0.05-0.45	6
T-1	3.16	1.65-5.37	6
T-2	1.42	0.91-2.75	6
TE-1	3.78	2.94-4.62	2
TE-2	2.64	0.17-5.10	2

*summarized from Table 6.1

Time series plots of oil content on *the* various plots provide a better index of the changes that resulted from exposure to tidal and wave action (Figs. 6.1 to 6.6).

The trends for the control plots (Figs. 6.1 and 6.2) show considerable temporal variation of hydrocarbon content. The variation is likely an artifact of the plot not being oiled uniformly and, to a lesser extent, variation in sampling technique (in future studies, it is suggested that a greater number of samples be taken on the control plots). The trends do suggest that the mean oil content remained relatively constant during the study (plot T-2 showed an increase during the study, probably due to the reasons mentioned above).

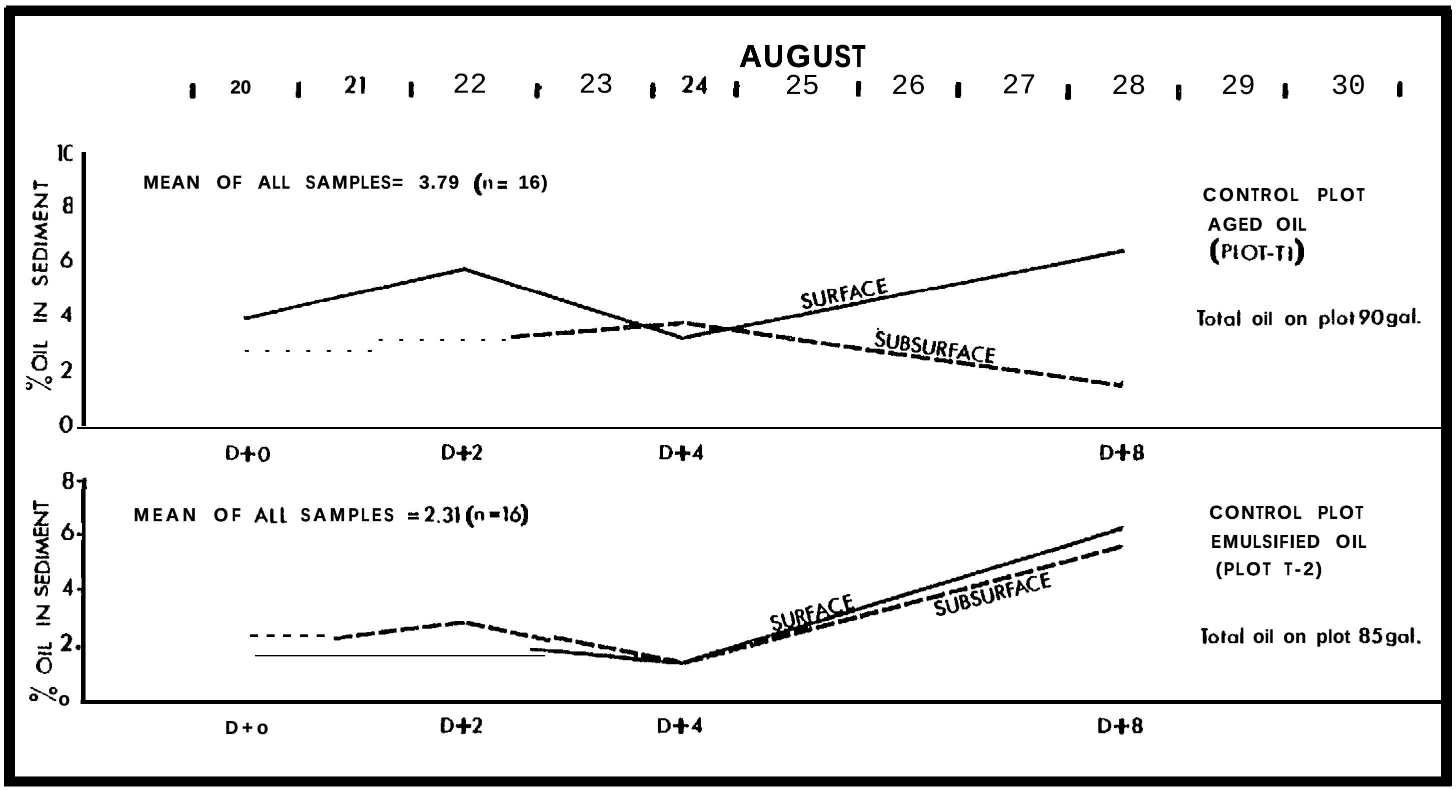

Figure 6.1 Time series plot of the sediment sample hydrocarbon content from control plots, T-1 and T-2.

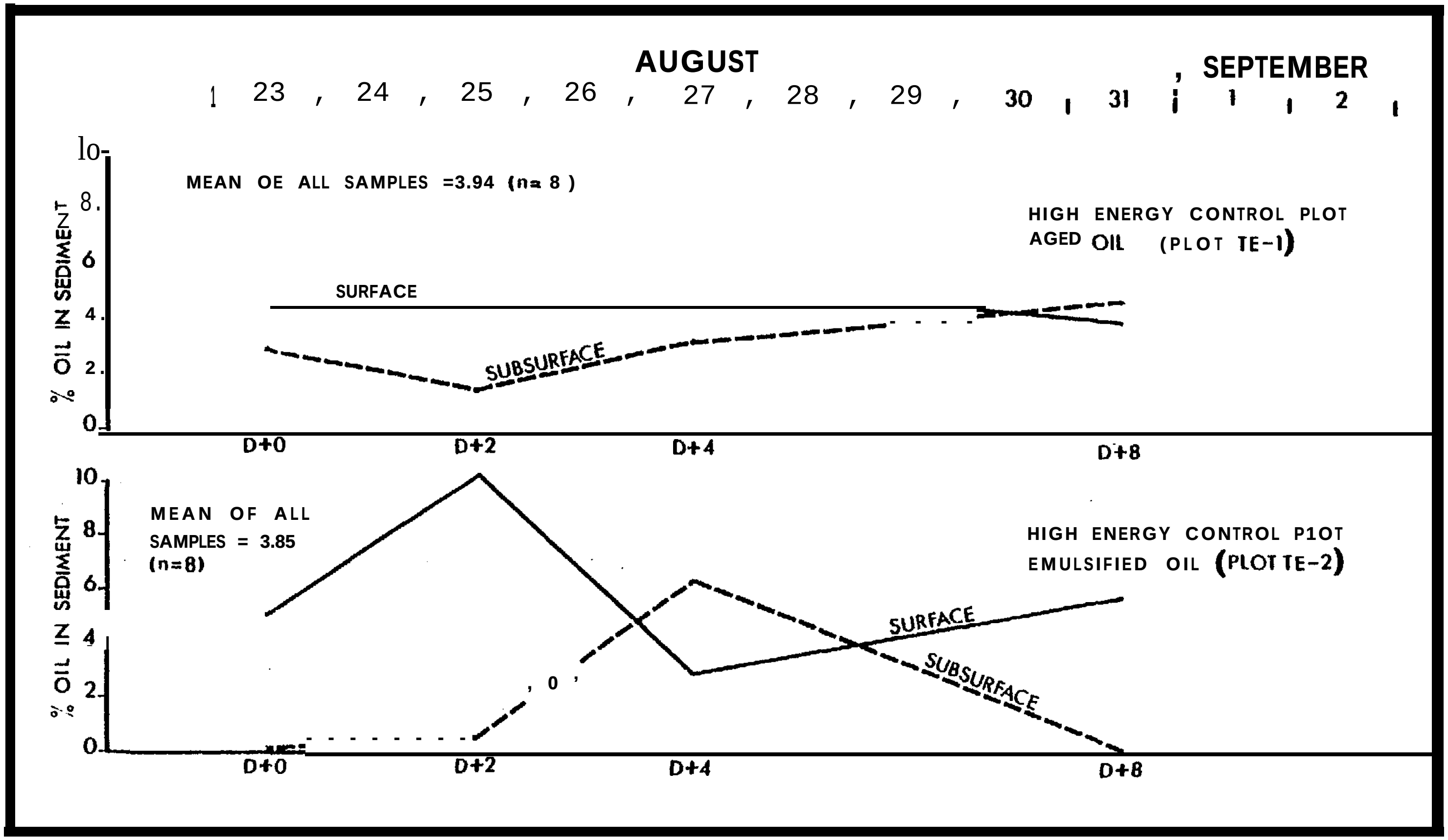

Figure 6.2 Time series plot of the sediment sample hydrocarbon content from the backshore control plots, TE-1 and TE-2.

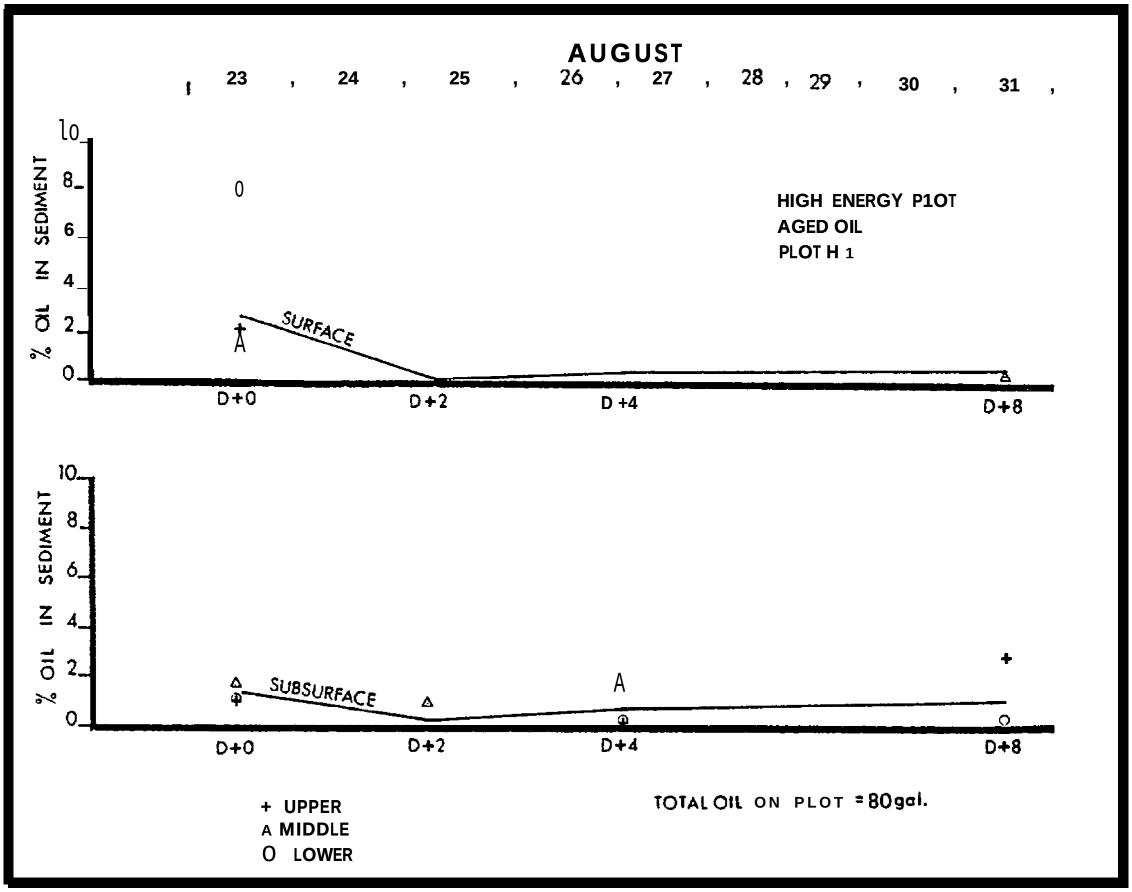

Figure 6.3 Time series plots of the sediment sample hydrocarbon content from the high-energy, aged oil plot H-1.

The trends in plots exposed to the marine processes are more distinct than those of the control plots. Oil contents in the high-energy, aged oil plot (H-1) were initially about 2-3 percent (Fig. 6.3), however, as a result of high wave action and the redistribution of sediment within the plot, surface oil content decreased to less than 0.1 percent while subsurface oil content remained at about 1 percent. A more detailed explanation of the morphologic changes chat caused these changes is included in Section 7.0.

Changes in the high-energy, emulsified oil plot (H-2) showed a similar trend - initial oil contents from 1 to 2 percent with a rapid decrease to less than 0.1 percent by the second day after the oiling (Fig. 6.4). The reason for lower subsurface values on this plot was the result of

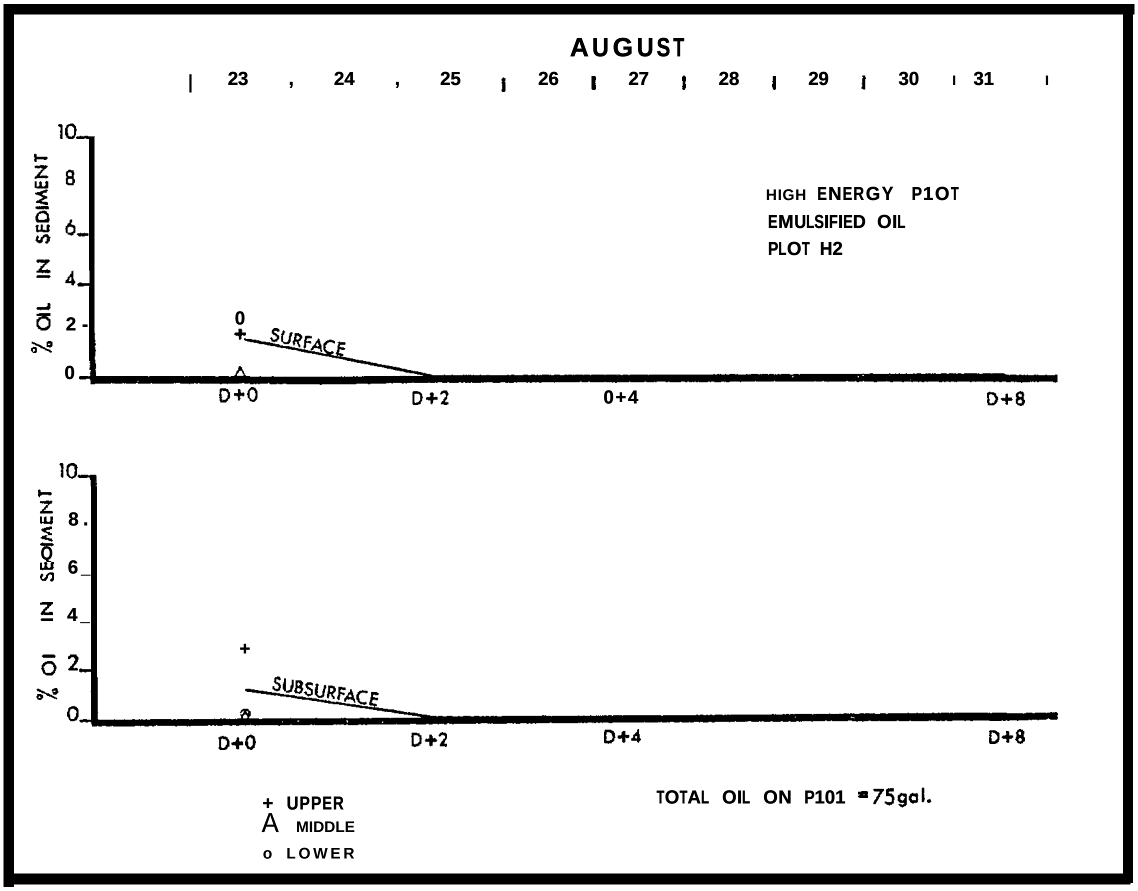

Figure 6.4 Time series plot of the sediment sample hydrocarbon content from the high-energy, emulsified oil plot H-2.

erosion of surficial and subsurface sediments immediately after the initial sampling (again, see Section 7.0 for a more detailed explanation), and the poor adhesion properties of the emulsified oil to sediment particles.

Changes in total hydrocarbon content of the low-energy, aged oil plot (L-1) are shown in Figure 6.5. Oil contents on this plot were initially about 2 percent and decreased slightly during the observation period to about 0.5 percent on the surface and between 1 and 2 percent in the subsurface samples (mean subsurface sample depth was 4-8 cm). As expected, the absence of mechanical wave energy during the study resulted in relatively small changes to the initial oil contents on this plot.

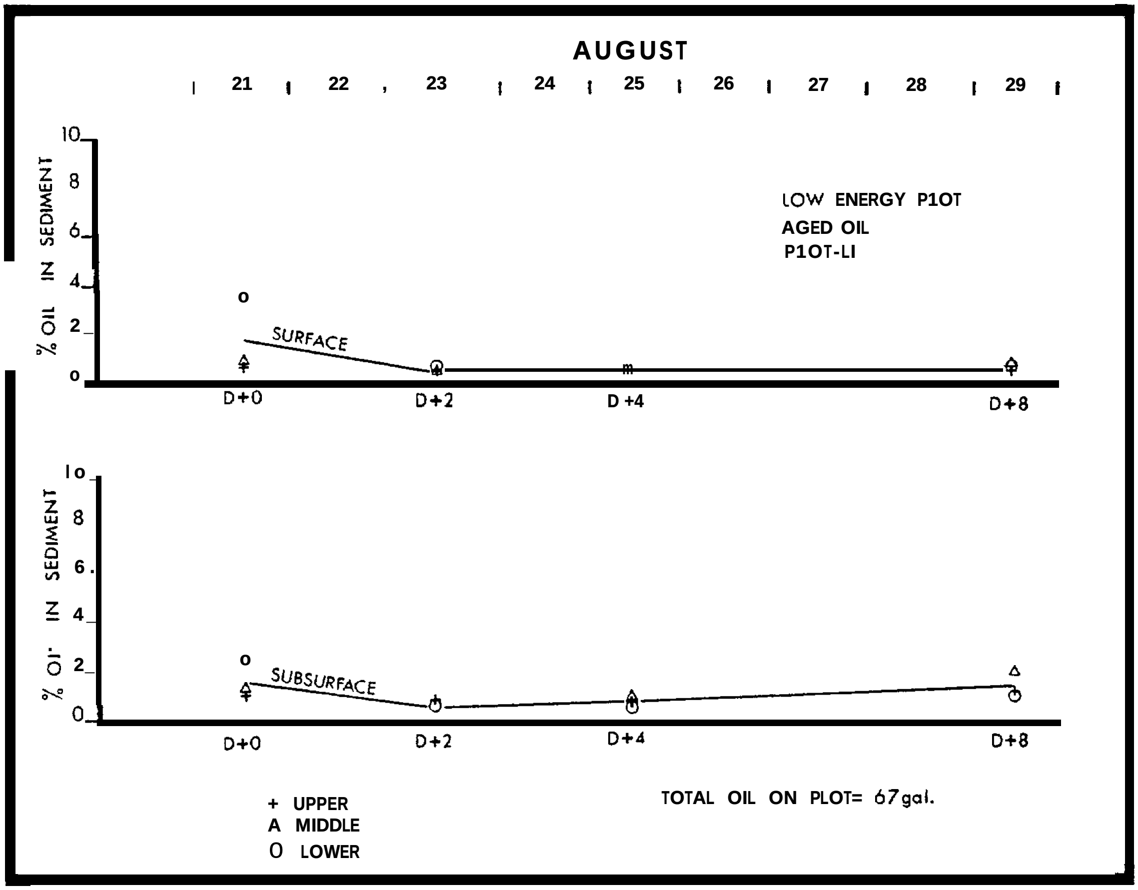

Figure 6.5 Time series plot of the sediment sample hydrocarbon content from the low-energy, aged oil plot L-1.

The total hydrocarbon time series trend of the low-energy, emulsified oil plot shows some very distinctive features (Fig. 6.6). Initial oil content values were less than 0.3 percent and decreased to less than 0.01 percent during the study. The initially very low oil retention of the sediments was related to the presence of the groundwater table in close proximity to the surface and to the poor adhesion properties of the emulsified oil to the beach sediment. Of the 0.42 m^3 or 254 1 (90 Imp. gallons) of water-in-oil emulsion applied, over 0.22 m^3 (50 Imp. gallons) were recovered in runoff ditches at the base of the plot. Only half the normal application amount was applied to this plot because of the over 50 percent runoff from the first oiling pass.

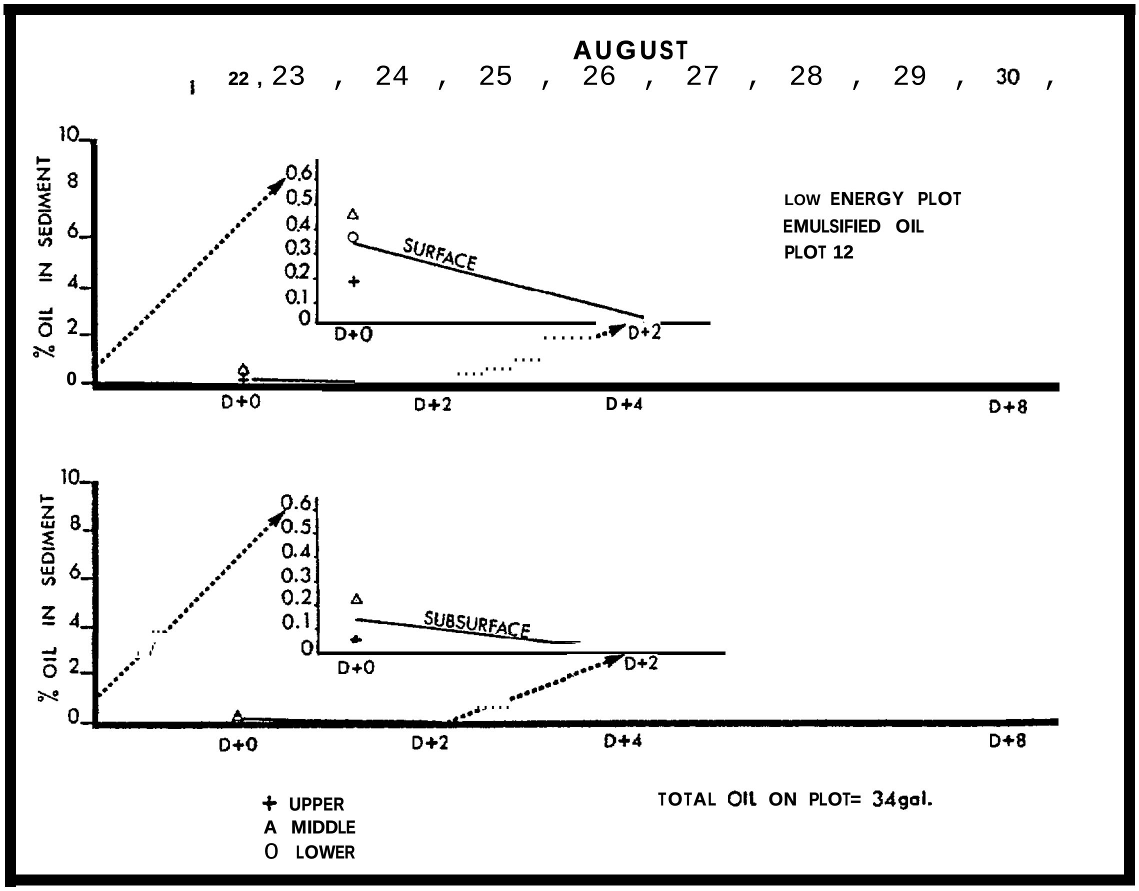

Figure 6.6 Time series plot of the sediment sample hydrocarbon content from the low-energy, emulsified oil plot L-2, (insets are at an expanded scale).

6.3 Compositional Changes in Hydrocarbon Content

Compositional changes in the hydrocarbon content during the experiment were estimated from GC/MS analysis of the oiled sediment samples. This analysis technique allows the changes due to various weathering processes to be monitored. Typically, the lighter oil fractions, the aromatics, are removed quickly by evaporation, usually within a matter of hours ; heavier fractions show slower rates of change generally as a function of the microbial decomposition of the oil.

Figure 6.7 shows a set of GC analysis curves for the low-energy plot, L-1.

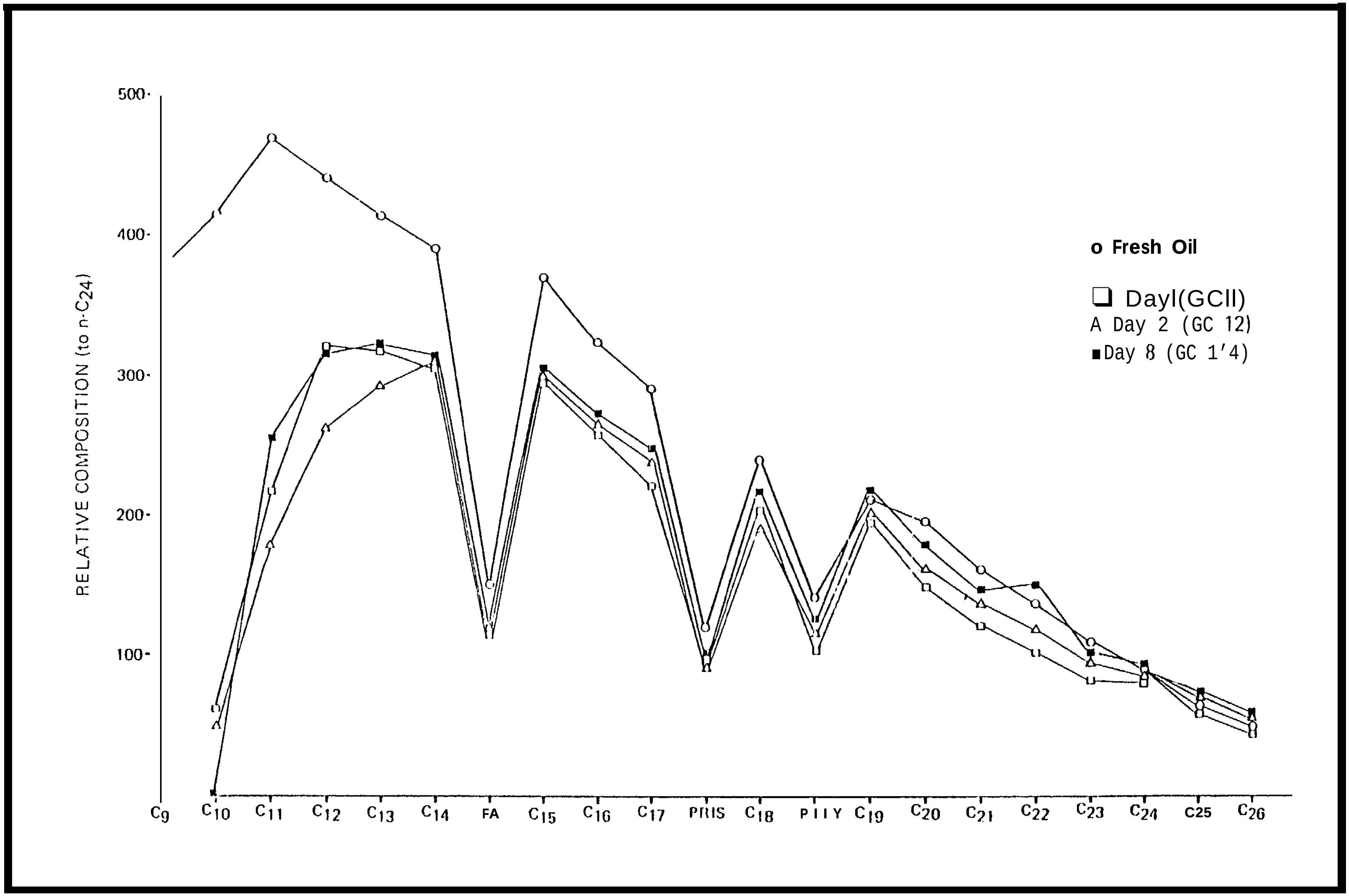

Figure 6.7. Comparative saturated hydrocarbon composition of Lago Medio crude oil, determined from GC analysis of Plot L-1 samples.

The curves, which are typical of most of the GC analysis performed for this study, show two significant features. First, most of the compositional change was in the lighter fractions, C_9 to C_{17}; this change is indicated by the difference between the "fresh oil" curve and the Day 1 curve. The second significant feature evident from the plots is that the compositional changes occurred rapidly, prior to Day 1, with little subsequent change. These changes are a result of the lighter aromatic fractions being removed by evaporation processes immediately after the spill. Changes to the heavier fractions are likely to be much slower and largely a result of microbial decomposition of the oil.

Several problems, which prevent a more detailed interpretation of weathering characteristics, exist with the compositional change curves. First, the plots do not always show a systematic weathering progression and curves for Day 8 commonly show less weathering than do the curves for Days 1 and 2 (e.g., Fig. 6.7). This suggests that the test plots were not homogeneous with respect to weathering characteristics (e.g., samples collected on Day 8 may have been partially covered and protected from weathering processes) , and that the subsamples drawn for the GC analysis may have compounded this problem. Hopefully, the resulting inconsistencies will be minor in comparison to the year-to-year changes.

A second problem, which interferes with the interpretation of weathering characteristics, is the compositional variation of the oil that was applied to the plots. The compositional curve (not shown) for a composite aged oil sample (drawn from several barrels prior to the oiling) commonly shows a greater degree of aging than does the oil analyzed from the plot samples. This aging inconsistency suggests that significant variations in oil composition existed between barrels and that, as a result, the oil applied to one plot may have differed substantially from oil applied to another plot. Because of the uncertainty of the composition of the oil applied to the plot, it is difficult to quantitatively estimate the percentage of oil lost due to atmospheric weathering processes.

6.4 Estimated Spilled Oil Budget

Knowledge of both the change in total hydrocarbon content of the sediments and the compositional change due to weathering processes allows estimates of the relative importance of the various weathering processes and permits construction of an oil spill budget for the observation period.

The major processes affecting the redistribution of the oil include (a) atmospheric evaporation, (b) the combined action of waves and tides, and (c) microbial decomposition of the oil. Atmospheric evaporation of the lighter oil fractions usually occurs within hours after the spill and usually accounts for approximately 5 to 10% of the total weight loss (Boehm, personal communication). Due to the problems associated with the GC analysis discussed above, it is not possible to estimate the amount of oil lost as a result of evaporation from the experimental plots; however, because the oil was artificially aged 8% by weight, it is probable that most of the aromatics had already been removed prior to the spill. For purposes of constructing an oil budget, it is assumed that the amount of oil lost due to atmospheric weathering was small.

Changes of total hydrocarbon content due to wave and tide action were significant in terms of an oil budget. Table 6.3 shows the percentage of oil remaining on the high- and low-energy intertidal test plots after 8 days. Several important weathering features are readily apparent from the table and include:

- a generally large reduction of oil in the sediments as a result of marine weathering processes,
- a higher percentage removal of emulsified oil, probably caused by its less adhesive nature,
- a higher percentage removal of oil from surface layers in comparison to the subsurface layers (see Section 7.0).

From these figures, an approximate oil budget can be estimated for both

TABLE 6.3 Percent Change In Initial Oil Loading After 8 Days

TEST PLOT	AVERAGE INITIAL LOADING % OIL IN SEDIMENT		AVERAGE FINAL LOADING (AFTER 8 DAYS) % OIL IN SEDIMENT		% OF INITIAL OIL LOADING REMAINING AFTER 8 DAYS		
TEST PLOT	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface & Subsurface
H-1 (aged)	3.6	1.2	0.12	1.0	3.3	83.0	43.0
H-2 (emul.)	1.37	1.05	0.002	0.006	0.14	0.40	0.27
L-1 (aged)	1.71	1.55	0.65	1.39	38.0	90.0	63.8
L-2 (emul.)	0.34	0.14	0.013	0.008	3.8	5.7	4.8

the aged and emulsified forms of oil used in the experiment. It should be mentioned, however, that oil removal was not solely a function of the weathering processes, but rather was also partially dependent on the oil retention characteristics of the beach sediment.

The oil budget (Table 6.4) is estimated by assuming that atmospheric weathering was small, that high wave action was the most important removal process on the high-energy beach (see Section 7.0), that waves on the low-energy beaches were essentially non-existent and therefore tidal action removed all oil from these beaches, and that microbial decomposition was minimal.

The most surprising result of the oil budget is that tidal action is fairly effective at removing oil from low-energy beaches, largely as a result of the higher water tables present in these beaches. The observed differences between the emulsified and aged oil retention characteristics resulted largely from differences in morphologic response of the beaches to wave action and in initial beach retention characteristics rather than from differences in oil response to weathering processes (see Section 7.0 for additional discussion).

TABLE 6.4 Estimated Oil Budget

WEATHERING PROCESS	PERCENT OIL REMOVAL HIGH ENERGY AGED	PERCENT OIL REMOVAL HIGH ENERGY EMULSIFIED	PERCENT OIL REMOVAL LOW ENERGY AGED	PERCENT OIL REMOVAL LOW ENERGY EMULSIFIED
Atmospheric Evaporation	<5	<5	<5	<5
Wave Action	∿50	∿90	<1	<1
Tidal Action	?	?	∿29	∿90
Microbial Decomposition	<1	<1	<1	<1
(Residue)	43	0.27	64	4.8

7.0 BEACH MORPHOLOGY CHANGES

Qualitative and quantitative observations of beach morphology changes were noted during the study and proved to be useful in documenting the dispersal of the oil spilled on the beaches. The observations discussed in this section are limited to the high-energy intertidal beach plots, which underwent significant change following the spill; no morphologic or textural changes occurred on the low-energy plots during the brief period following the controlled spill.

An understanding of the beach dynamics is important in evaluating the observed changes in total hydrocarbon content (Figs. 6.3 and 6.4). Despite the two plots being located in close proximity to each other (within 10 m), the plots underwent distinctly different morphologic change, which might be interpreted as variable weathering responses of the two different oil forms, Discussion of the specific morphologic responses that occurred, their influence on the oil dispersal, and the possible consequences of the change are included below. Also included is a discussion of the beach "ice mounds" noted around Ragged Channel and Z-Lagoon during the break-up season (Dickins, 1981). The "ice mounds" may represent a feature and process that is important in mixing beach sediments and, as such, may be significant to the mechanical dispersal of oil in the shore zone.

7.1 Beach Profile Change

As mentioned previously, beach profile measurements were made daily on the high-energy, intertidal plots along the four survey lines at the ends of each plot (Fig. 4.9). The stakes at each corner of the plot established the survey line and served as temporary bench marks for measuring beach elevations (the chemical contractor continued to measure these stakes during the later part of the experiment). In general, a small gravel-pebble berm crest (Fig. 7.1) was present within the plot, with a gravelly sand beach face, inclined at approximately 10° (Fig. 4.10). The

Figure 7.1 Photograph of the high-energy, aged oil plot H-l immediately prior to oiling, showing the presence of a small swash and berm crest in the centre of the plot covered by a mat of kelp material. The burial of this kelp material was later evident in the cross-sectional trenches (see Fig. 7.5).

position of the berm crest and the vertical elevation of the beach face varied from day to day depending on the existing wave-energy conditions. Daily changes in the cross-sectional profiles of each of the high-energy plots (H-1, H-2) are shown in Figures 7.2 and 7.3 and indicate the sedimentation pattern and magnitude of beach variation.

The major events apparent in the beach profile changes are:

(1) a major erosional phase that occurred shortly after the oiling on the night of 23-24 August and that resulted from high-wave activity (wave heights greater than 1 m; wave periods 6-7 seconds).

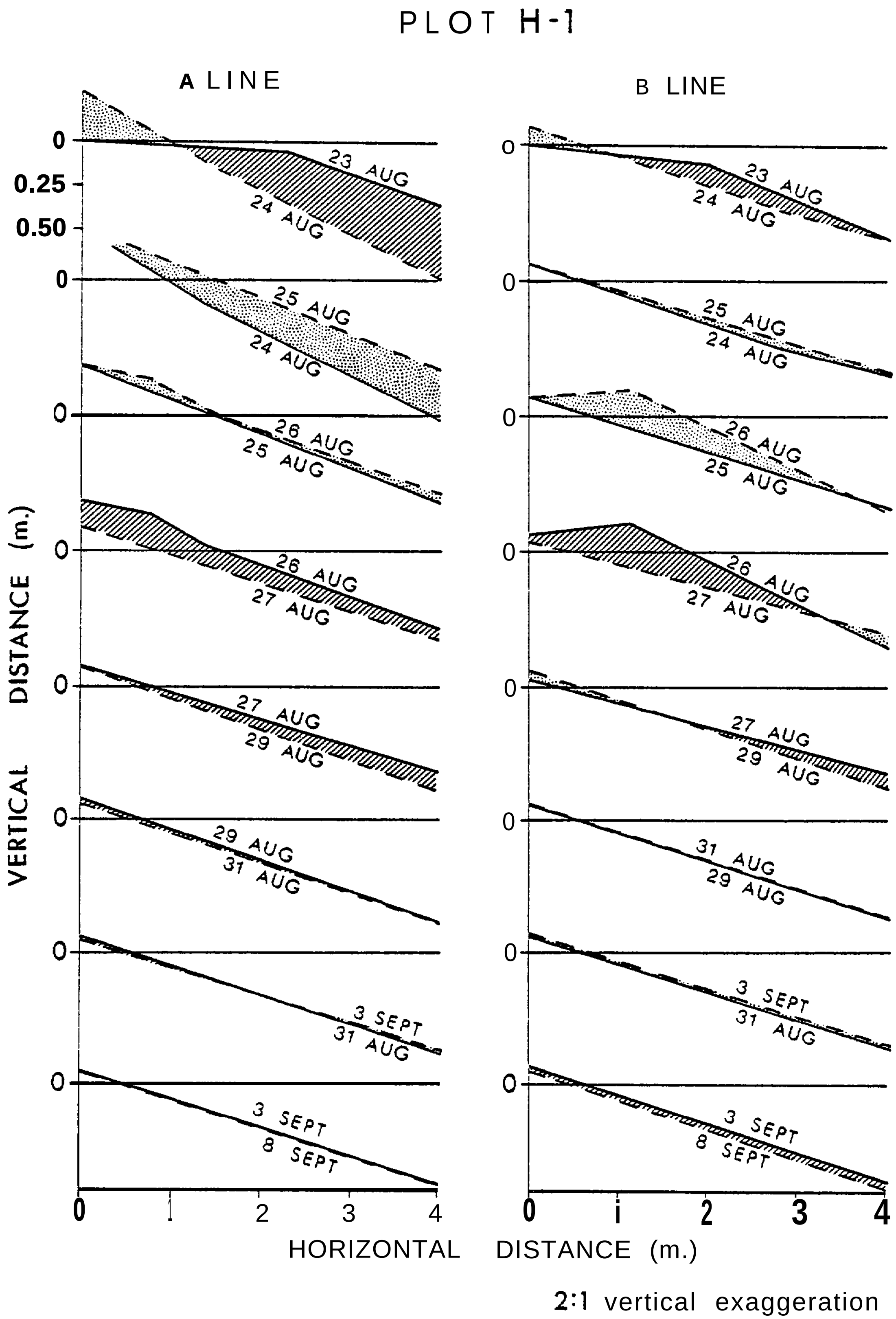

Figure 7.2 Daily beach profiles from the high-energy, aged oil plot H-1.

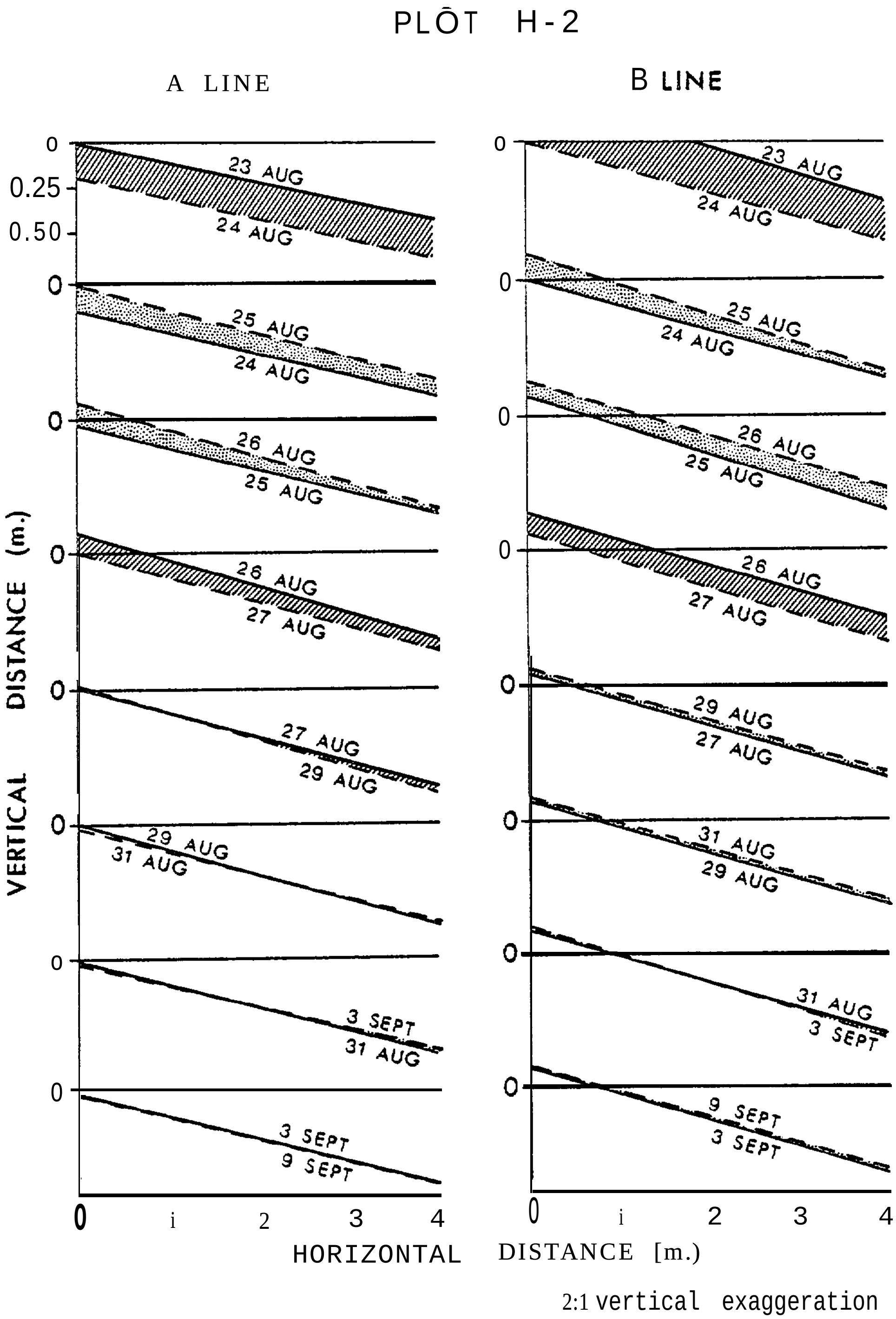

Figure 7.3 Daily beach profile changes from the high-energy, emulsified oil plot, H-2.

(2) A significant accretional phase on the 25th and 26th of August during quiescent wave conditions.

(3) A second erosional event or phase on the 27th of August, related to higher wave activity, which resulted from strong onshore easterly winds.

(4) A dormant phase from August 27th to September 9th when little change was noted.

Some of the smaller, more subtle changes proved to be significant in terms of the oil dispersal. The most important of these factors were: (1) the deposition of material on H-1 near the top of the plot (Fig. 7.2, top profile sets) , which buried the previously oiled surface, and (2) the relatively minor erosion of the lower portion of plot H-1, which, although removing oiled material, resulted in some of the oiled sediments remaining and later being buried (on 25 and 26 August). The greater amount of erosion, which occurred on H-2, the emulsified oil plot, removed almost all of the oil, except in the upper northern corner of the plot.

The sequence of events is illustrated more clearly by the time-series plot of volumetric change on the two test plots (Fig. 7.4). Volumetric changes indicate that plot H-2 underwent nearly twice the volumetric erosion of plot H-1 leaving very little oil within the plot. Also, although both plots showed net erosion initially, they had recovered to the original volume by the time of the second erosional event on the 27th of August (see the cumulative curve, Fig. 7.4). Following the second erosional event, very little recovery occurred.

The reason for the differential erosion of the two plots is unclear, although it probably resulted from an alongshore transfer of beach material to the north as a result of a horizontal circulation cell set up during the first storm. The consequences to the dispersal, however, are important.

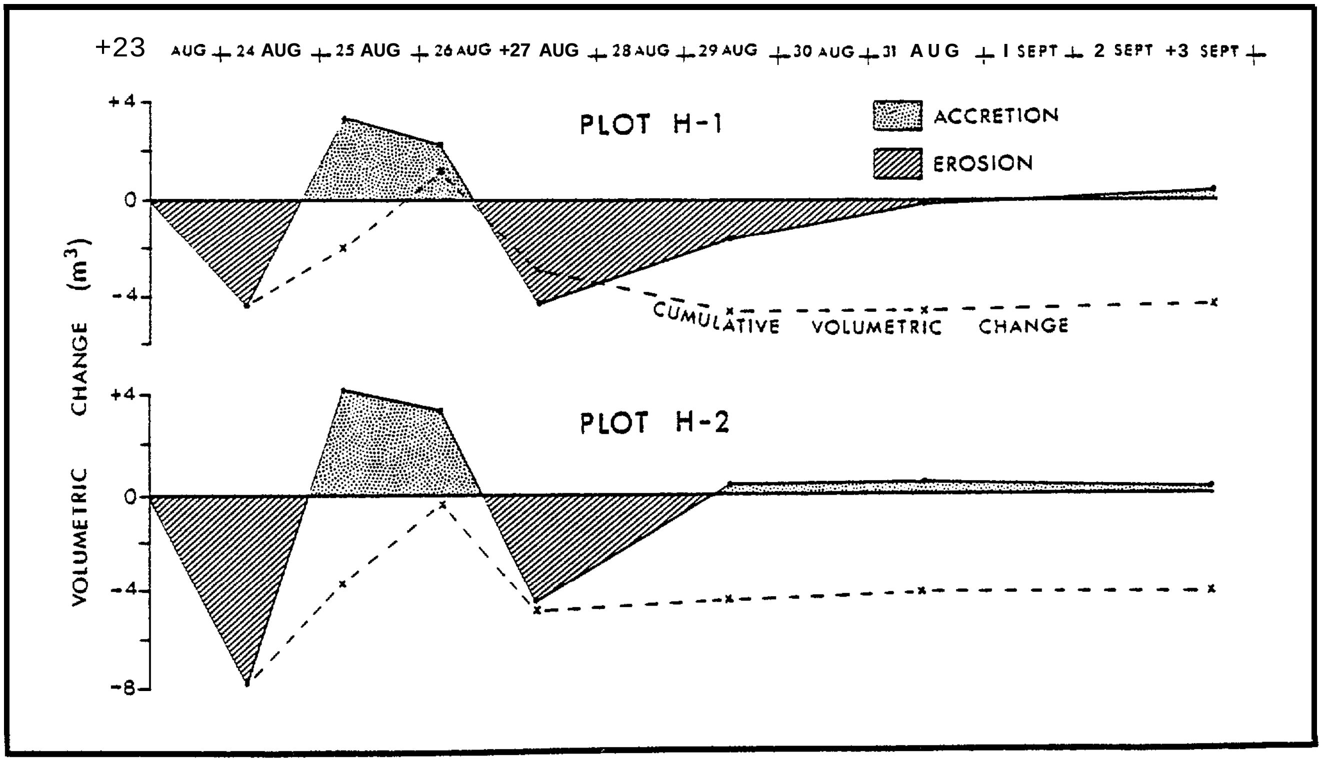

Figure 7.4 Time series of the total volumetric change for both of the high-energy oil plots, H-1 and H-2.

7.2 Related Mechanical Oil Dispersal

The beach erosion and accretion patterns that occurred shortly after the controlled spill had two very significant effects on the subsequent dispersal of the oil:

- Erosion in plot H-2 resulted in nearly complete removal of the emulsified oil from both the beach surface and subsurface immediately after the spill (see Fig. 6.4).
- Deposition and minimal erosion in the H-1 plot allowed the oiled sediments to remain and subsequently be buried.

Trenches through the plots illustrate the thickness and extent of the buried oil layer on 25 August, two days after the spill (Fig. 7.5). The oil layer was approximately 10-20 cm thick in both trenches, although only a small wedge of oiled sediments was present in plot H-2. The reversed

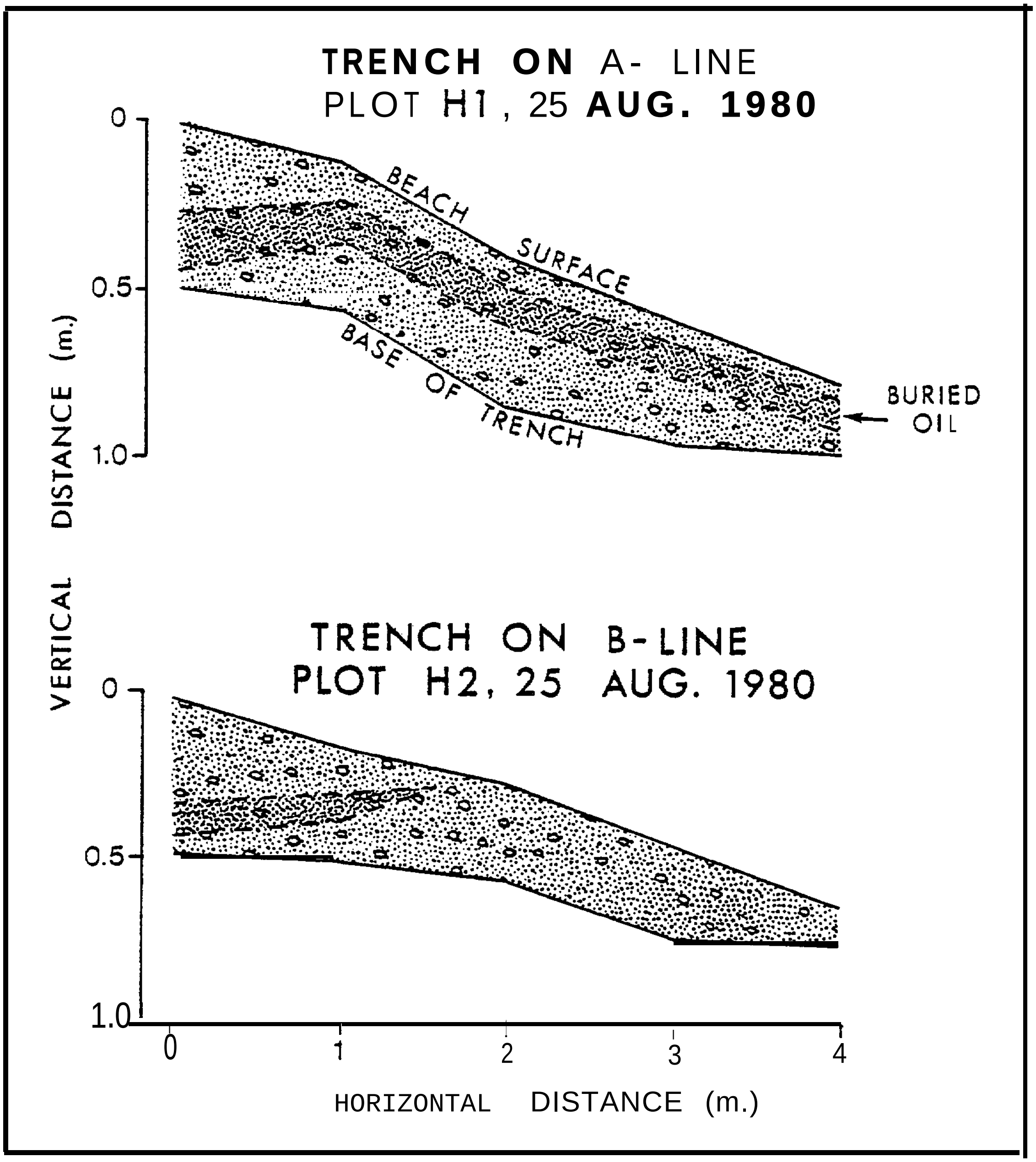

Figure 7.5 Buried oil layer as seen in trenches on 25 August (see Fig. 4.9 for location of trenches).

(landward) slope of the oiled layer in the H-1 trench (Fig. 7.5) reflects the original landward slope of the small berm crest present on the day of oiling (Fig. 7.1). Relatively little disturbance to the oiled layer occurred in the upper part of the plots as is evidenced by the presence of oiled seaweed, which was lying on the beach surface during the initial oiling (Fig. 7.6). The oiled layer in the lower portion of the trench

Figure 7.6 Photograph of the buried oil layer (lying below the white line) on August 25th. The scale increments are 1 cm, and the arrows point to some buried oiled kelp. The presence of the buried kelp suggests that the deposition of material on top of the oil surface occurred with very little disturbance.

was probably eroded slightly on August 23rd and 24th before the new material on top was deposited.

On August 26th, the buried oil layer was still widespread under plot H-1 and mostly absent under plot H-2 (Fig. 7.7a.). Later that day and evening, strong onshore easterly winds caused increased wave activity and resulted in a second erosional event and material being removed from the beaches (Fig. 7.4). The oil distribution map for August 27th (Fig. 7.7b) indicates that the thickness of the buried oil layer on plot H-1 decreased as a result of the higher wave action. At the end of the observation period (27 August 1980), a partial buried oil layer still existed under the

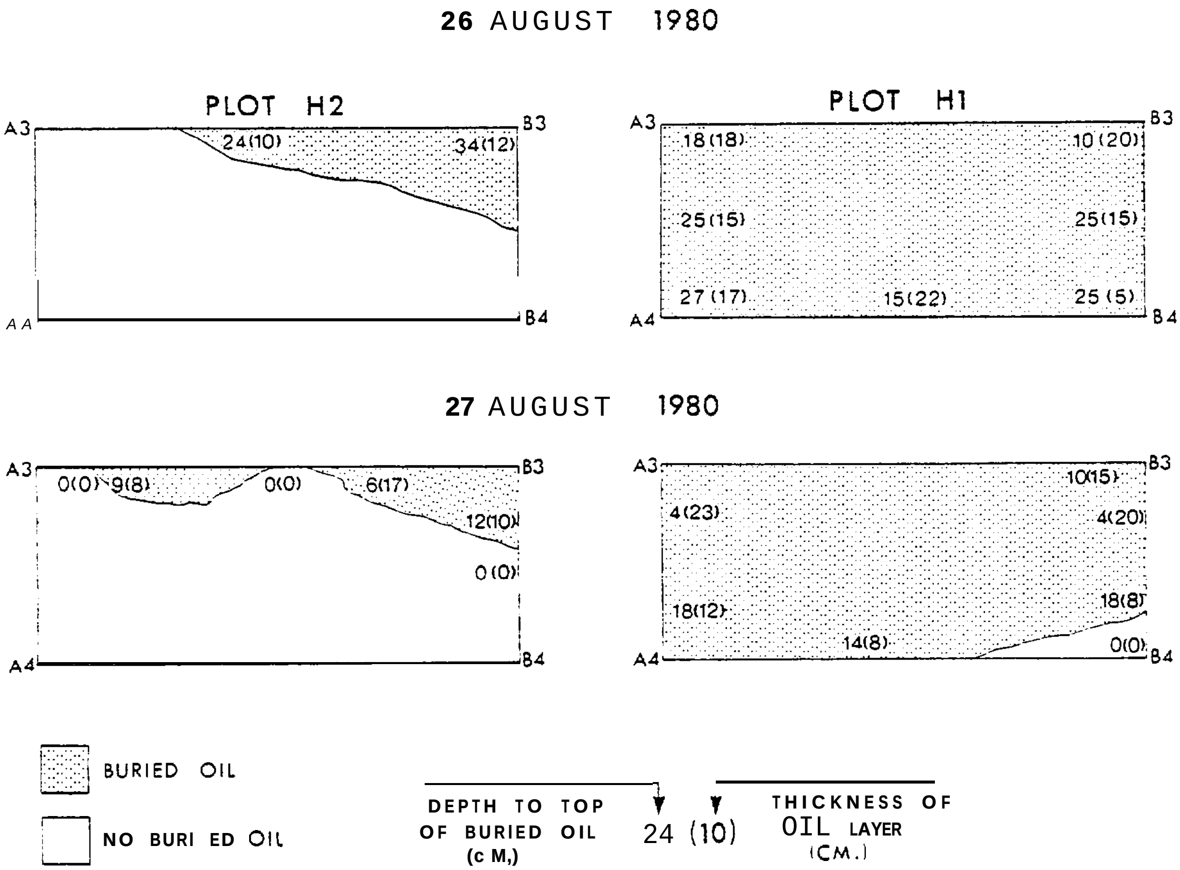

Figure 7.7 Oil distribution maps showing the depth and thickness of buried oil on August 26th and 27th.

two high-energy plots. Since the morphologic changes that occurred after the 27th were small (Fig. 7.4), the potential for preservation of the oil layer was high, in the event that no large fall storms occurred.

The implications of these changes are important to the interpretation of oil dispersal. If these morphologic changes had not been observed following the spill and one relied solely on the total hydrocarbon analysis to indicate the trends in oil dispersal (Figs. 6.3 and 6.4 and Table 6.4), then one would have drawn the conclusion that aged oil was more resistant to mechanical dispersal by wave action than was the emulsified oil. What in fact happened was that spatial variations in the physical processes over very short distances produced the observed changes. In that respect, the test control plots were not well chosen; ideally the plots should have been chosen such that the distribution of physical processes was uniform over the entire test location. Future plot sitings should be located, whenever possible, on open, long sections of coast where the spatial distribution of processes is uniform.

7.3 Ice Effects on Oil

No direct observations of ice effects on oil dispersal were made during the study, however, it is possible to estimate probable effects of ice in redistributing the spilled oil. A discussion on the probable influence of "ice mounds" on the redistribution of oil is also included.

The low-energy beaches in Z-Lagoon are protected from major ice movements and are not expected to be substantially reworked by ice gouging, although the concentration of boulders near the high-water line (see Fig. 4.11a) suggests that some redistribution of sediments by ice may occur. Ice-push events were noted at the high-energy test site (H-1, H-2; Bay #102) prior to the oiling (Dickins, 1981). As a result of the relatively open exposure to ice movement within Eclipse Sound, ice push on these beaches is likely to be a common phenomenon and it is estimated that approximately 25-50% of the upper 0.3 m of beach sediments will be reworked on an annual basis. The important effect of ice gouging in terms of oil dispersal is that buried oil sediments may be brought to the surface where they become exposed to the cleaning action of the waves. As such, ice push would likely enhance dispersal of oil from arctic beaches.

The action of ice against the shore is also likely to result in a net onshore movement of beach material. It is possible that some sediment could be transported above the normal limit of wave action by ice override events and, in this case, the dispersal and degradation of oil in the transported sediments would be retarded. The amount of sediment redeposited in this manner is very small (Hume and Schalk, 1964) and, in general, the effects of ice action on beaches would tend to enhance oil dispersal.

The presence of "ice mounds", which are of unidentified origin, on a number of the Cape Hatt area beaches may represent a process that is important to the redistribution of beach sediments in the shore zone. Dickins (1981) notes that the "ice mounds" were relatively linear, generally continuous, up to 1 m high, parallel to the beach, and usually located between the low- to mid-water lines. The "ice mounds" were frequently covered with sediment ranging from sand- to boulder-sized material and in at least one case sediment was incorporated within the "ice mound". Two general types were distinguished: (a) long, continuous "ice mounds", which were most common in Ragged Channel, and (b) discontinuous, irregular "ice mounds" noted in Z-Lagoon (Blackall, personal communication). Time lapse films of nearshore breakup showed that the "ice mounds" were relatively resistant to melting and suggested that the "ice mounds" were composed of fresh ice, free of brine pockets (Dickins, personal communication).

Morphologically similar ice features have been observed on arctic and subarctic beaches and the form is collectively referred to as an ice foot (e.g., see Dozier et al., 1976; Moign, 1976; Owens, 1976; Owens and McCann, 1970; Short, 1976; Short and Wiseman, 1973; Taylor and McCann, 1976). Generally the ice foot forms from the accumulation of spray and swash in the intertidal zone, although an ice foot may include ice-push blocks, beach sediments, and snow. Observations of ice-foot features in the Canadian Arctic indicate that they are common features of the lower intertidal zone and that they may persist over a period of several years (Taylor and McCann, 1976). Similar features observed in Spitsbergen occasionally include pebble-cobble sized material on the ice foot surface (Moign, 1976, Fig. 8), and residual ice foot and ice-push mounds in the Great Lakes show a very similar morphologic expression to those residual mounds observed in the Cape Hatt vicinity (Davis et al., 1976, Fig. 13).

The origin of the "ice mound" features is critical to the interpretation of the potential effects on the mixing of beach sediments and of the dispersal of oil in the beach sediments. If the "ice mounds" have originated by the process responsible for ice-foot formation, that is, largely the accumulation of frozen swash and spray in the intertidal zone, then the effect on redistributing sediments in the beach zone, particularly the upper intertidal zone where oil collects, is expected to be minimal. The larger sediments incorporated in the observed "ice mounds" may have resulted from wave impact against a relatively steep ice face (see Dozier et al., 1976, Fig. 6 for an illustration of such a process).

If the "mound" originated due to groundwater extrusion during freezing (Fig. 7.8), the process may cause the flushing of oil from within the

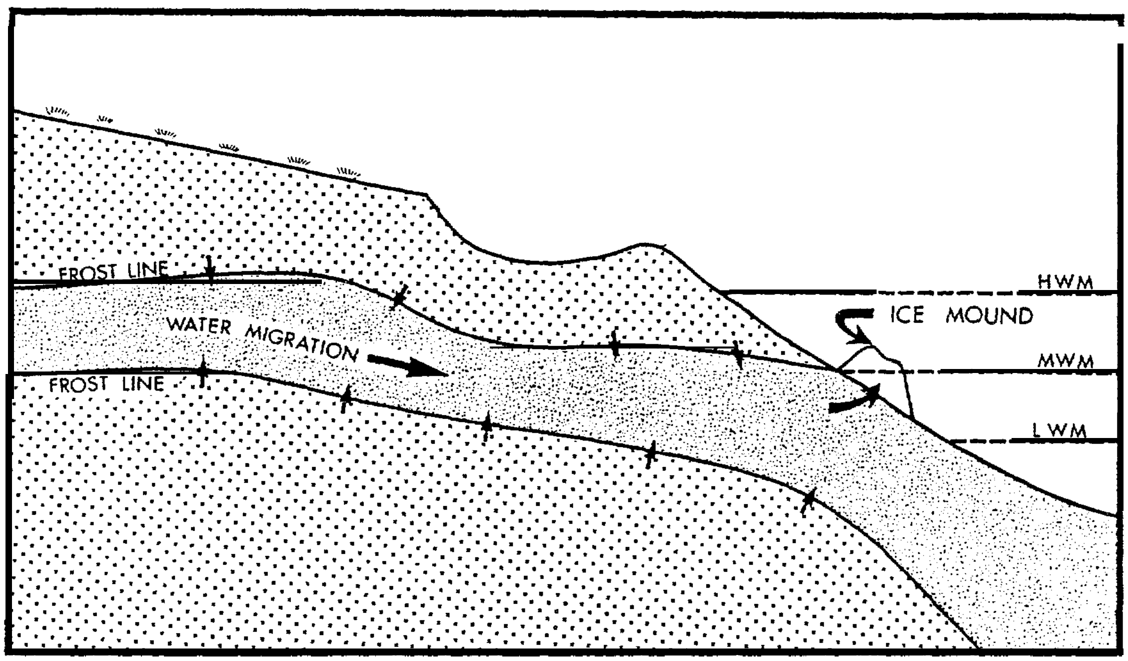

Figure 7.8 Possible mechanism of "ice mound" formation due to the extrusion of groundwater into the intertidal zone.

sediments and is likely to mix the beach sediments. As such, this process may be significant to the redistribution of oil stranded on arctic beaches, although as mentioned previously the process is likely to be confined to beaches that contain a significant fraction of fine sediments and, as such, may be limited to the lower energy arctic beaches. Recommendations for further study of the “ice mound” features are included in Section 9.0 and Appendix A.

8.0 TEMPERATURE AND RADIATION MEASUREMENTS

One of the oiled control plots (aged oil) and a non-oiled plot were instrumented for measuring net surface radiation and subsurface ground temperatures. The objective of this component of the experiment was to evaluate the effects of spilled oil on the near surface temperature regime and on the development of the permafrost active layer. If the presence of spilled oil significantly raised subsurface temperatures and increased the active layer depth, substantially greater amounts of littoral materials would then be available for reworking by littoral processes. Also, where thaw susceptible soils occur, which includes much of the western Arctic, thaw settlement instabilities could result from the presence of spilled oil in backshore areas. Thus , the experiment was designed as a preliminary test to monitor ground temperature changes caused by the presence of spilled oil.

8.1 Ground Temperature Measurements

Ground temperatures in the active layer were monitored in the oiled and non-oiled plots with two thermistor rods (Fig. 8.1). These were the control plots located in the backshore (Fig. 4.4) and, although not under the active influence of marine processes, they were located on relict beaches and are comprised of material similar to the present beaches. The rods were placed with thermistors at the 10, 20, 30, 40, 50, 60, and 70 cm depths. Because the rods were installed in mid-August, it was not possible to penetrate the frost table at about 80 cm.

Ground temperatures were measured daily from the day of oiling (20 August 1980) over a 12-day period using a Wheatstone Bridge. Results are plotted in Figure 8.2.

Figure 8.1 Photograph of the control test plot sites, T-1 and T-2, showing the net radiometer instrumentation in the centre of the photo and the position of the two thermistor rods, indicated by the arrows.

Comparison of the temperatures measured in the plots indicates that the ground beneath the oiled plot was significantly warmer than the non-oiled plot. The time series plot of temperature at the 10, 40, 70 cm depths (Fig. 8.2a) shows the trend. Surface temperature in the upper 10 cm was initially colder under the oiled sediments and subsequently warmer by approximately 1°C; temperature trends at the 40 cm depth were similar in that ground temperatures were warmer beneath the oiled plot by a little more than 0.5°C. At the 70 cm depth where ground temperatures were generally less than 1°C, sediments were warmer under the oiled plot by about 0.25°C.

The mean daily temperature difference from all levels (Fig. 8.2b) also indicates that the ground temperatures were higher under the oiled

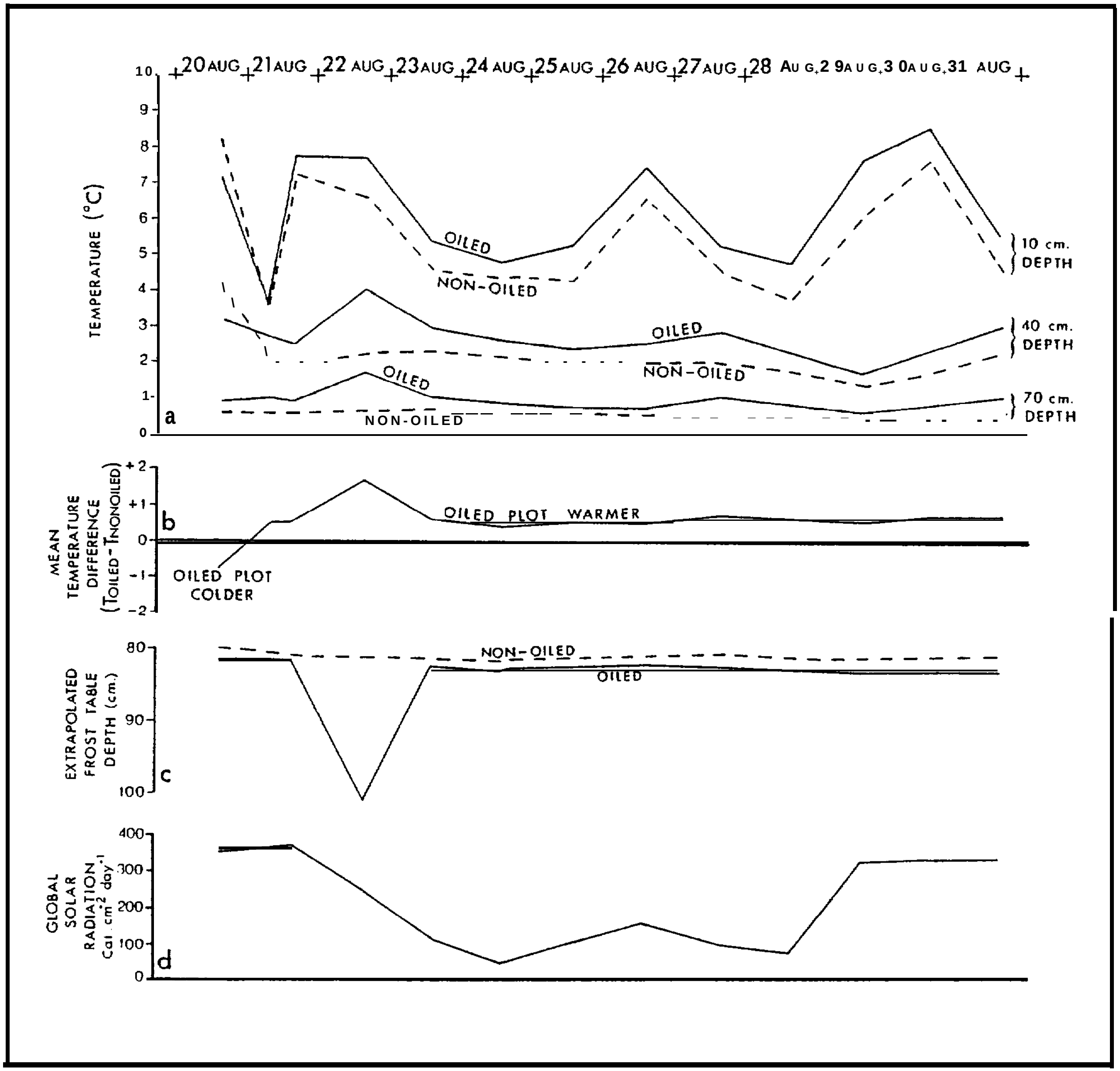

Figure 8.2 (a) Time series plot of the ground temperatures at various depths below the aged oil control plot T-1, and a nearby non-oiled plot, (b) mean temperature differences between the oiled plot and the non-oiled plot, (c) estimated frost table depth based on extrapolated temperature profiles, and (d) global solar radiation.

plot and that the mean difference increased from 0.5°C to 0.75°C during the study (ignoring the point on 22 August).

By extrapolating the temperature profiles, the depth of the frost table (0°C isotherm) was estimated (Fig. 8.2c). The large increase shown for the oiled plot on 22 August is an artifact of an anomolous temperature profile, which occurred on that day, and does not reflect the true frost table depth. Frost table depths were similar under both plots (80 to 85 cm). During the study, the estimated frost table depth increased at both plots but at a slightly greater rate under the oiled plot.

The preliminary results from the thermistor rod measurements indicate a definite influence of spilled oil on subsurface ground temperatures. Ground temperatures under the oiled plot were in all cases greater than under the non-oiled plot, except during the initial part of the experiment. The temperature difference tended to increase during the study, and there is slight suggestion that the oiling may have caused an increase in the frost table depth.

8.2 Radiation and Heat Budget Measurements

Unfortunately, the radiation-heat budget experiment could not be completed due to the lack of proper equipment (high sensitivity anemometers, soil heat flux meters, calibrated radiometers). Global solar radiation (incoming short-wave radiation) was measured at the BIOS camp and is plotted in Figure 8.2d. The correlation between surface ground temperature and global radiation measurements indicates a causal effect relationship and some qualitative estimates are possible regarding the effect of oil on ground temperature measurements.

The oiled surface was much darker and, as such, has the capacity to absorb increased amounts of net solar radiation. Any increase in the amount of net solar radiation (Q_N) must be balanced by changes in the latent heat flux from the surface (Q_E), the sensible heat flux from the surface (Q_H), or the flux of heat into the ground (Q_G). The balance is expressed by equation 8.1.

$$Q_N = Q_E + Q_H + Q_G \tag{8.1}$$

Without significant changes in the surface roughness of the plots, Q_E and Q_H would not be expected to change, hence, increases in net radiation values would be largely balanced by increases in the ground heat flux. The correlation noted between surface ground temperatures and global radiation values (Fig. 8.2) indicates that solar radiation was the significant parameter controlling ground temperature variations, and it is suggested that the increase in ground temperatures noted under the oiled plot during the study resulted from increased net radiation on the plot surface. The implications of this observation are important in that increased ground temperatures may result in increased microbial activity in the surface sediments and, that active layer thickness may be increased, which would allow a greater amount of sediment to be reworked by marine processes.

9.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the preliminary results of the Phase I Shoreline Test Programme, it is possible to draw conclusions and to provide recommendations that may improve the performance of the second phase of the experiment to be conducted in 1981. The recommendations will serve as a basis for further discussion and will be incorporated into the 1981 design considerations.

9.1 Conclusions

The major objectives of the Phase I Shoreline Test Programme were to (a) test methods of spilling oil on shorelines in preparation for the countermeasures tests to be conducted during the Phase 11 Test Programme in 1981, and (b) to evaluate the weathering characteristics of two forms of oil (aged crude oil and emulsified,aged crude oil) on shorelines of differing wave-energy levels and ice-scouring activity. In general, the experimental programme successfully met these objectives. The observations from the Cape Hatt field-test programme and preliminary analysis of the sediment hydrocarbon contents lead to the following specific conclusions.

(1) The oil spill application system performed well and proved flexible under beach conditions of varying sediment texture and slope. The most important problem with the system appeared to be non-uniformity of oil application; several improvements are recommended below, however, the primary geological variable in this type of experiment, the micro-topography of the beach surface, is a natural component of coarse-sediment beaches, so that some thinning and pooling of spilled oil would result even with more sophisticated application techniques.

(2) Although the weathering of the oil spilled on the supratidal control plots was expected to be miminal during the brief observation period following the spill, analysis of the sediment hydro carbon content showed significant variability during this 8-day observation period. A portion of this variability probably results from the collection of a limited number of samples from a non-uniformly oiled sediment and from the non-uniformity of the spilled oils. In any event, the variation will make comparison of the year-to-year weathering changes difficult, although the rate of weathering versus depth can stil be determined by comparing GC/MS results during the next few years. An improved sampling programme is recommended below.

(3) Mechanical dispersal of the oil from the intertidal test plots following a single oiling was relatively rapid and initial oil-in-sediment concentrations were substantially lowered during the period of observation. Specific observations include:

(a) Retention of emulsified oil on the beach plots was generally less than the retention of aged oil, partially as a result of poor adhesion properties of the emulsified oil (see also (4) below).

(b) Mechanical wave action was effective in dispersing the oil from the exposed beaches; from 50 to 90% of the spilled oil was removed within 48 hours of the spill as a result of wave action on the beach.

(c) Tidal action proved to be reasonably effective in removing the spilled oil on sheltered beaches not exposed to wave action; tidal action removed 30 to 90% of the spilled oil within the 8-day observation period and was most significant on beach sections characterized by a high groundwater table.

(4) Local variations in beach sediment characteristics and in beach morphology changes were partially responsible for the observed differences in the oil content of the sediments between the aged oil plots and the emulsified oil plots. These variations included:

(a) A lower oil retention on the low-energy emulsified oil plot (L-2) than occurred on the low-energy aged oil plot (L-l); due to a finer sediment size and higher groundwater table on the L-2 plot.

(b) Erosion of the beach surface of the emulsified oil high-energy intertidal plot (H-2) occurred during a period of high-wave activity, while at the same time sediments were deposited on the aged oil plot (H-l), resulting in partial burial of that oil.

These variations in beach response and beach sediment character were partially responsible for producing the observed oil retention differences between the emulsified and aged oil plots.

9.2 Recommendations

Recommendations, based on the above conclusions,which may improve the 1981 study are provided below:

(1) Refinement of the oil application system could provide a more uniform oil distribution. Possible refinements include:

(a) traversing the plot at higher speeds and making multiple passes over the plot, or

(b) winching the ATV in order to provide a more uniform speed.

(2) Collection of additional samples from the control test plots is necessary to compensate for non-uniform oiling of the plots. Analysis of the standard deviation trends in the samples suggests that approximately 20 subsamples must be collected in order to define the true mean value of the sediment hydrocarbon content. These additional samples will allow a meaningful comparison of year-to-year oil weathering characteristics.

(3) Considerable attention should be given to test plot selection. Differences in oil retention in the sediments results, to a large extent, from local (small-scale) variations in physical processes, rather than from variations between the physical characteristics of the two oil forms. Future selection of test sites should attempt to minimize the likelihood of alongshore variations in beach character or response.

(4) The effects of freeze-up and winter ice push on oil dispersal are unknown, due to the necessarily brief observation period which followed the spill. Consideration should be given to extending the observations to the autumn freeze-up period as well as to spring breakup when the effects of winter ice push might be observed. In particular, the origin of the "ice mounds" could be determined through a pre-breakup field investigation programme (see Appendix A).

It is anticipated that the implementation of these recommendations would improve greatly the effectiveness of the 1981 field experiments and would contribute to the understanding of weathering and of the mechanical dispersal of oil stranded on arctic beaches.

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APPENDIX A

RECOMMENDED "ICE-MOUND" OBSERVATION PROGRAMME

In view of the concern over the origin of "ice mounds" and their possible influence on the dispersal of oil from beaches, an observation programme is recommended to determine the mode of origin. The programme is outlined in two phases: (a) a reconnaissance-observation phase in which the "mounds" are trenched and sectioned prior to spring melt and the internal structures are documented, and (b) in the event that the "mounds" are identified as being of "groundwater extrusion origin", an instrumentation phase in which thermistor probes are installed across the beach to monitor freeze-back conditions. It should be emphasized that the second phase is only necessary should the first phase identify the "ice mounds" as a groundwater extrusion feature. If the "ice mounds" are, in fact, identified as an ice-foot feature then an instrumentation phase would not be necessary.

During the reconnaissance phase, "ice mounds" would be trenched cross-sectionally in order to observe the internal structures of the ice and the morphology of the interbedded sediments (e.g., see Owens, 1976; Short, 1976). Observations of this type would identify the "ice mounds" either as a swash-formed, ice-foot feature "or as a groundwater extrusion feature. Ice samples would identify the ice as either of groundwater origin or of seawater origin. The pre-melt "ice-mound" observations would be supplemented by a reconnaissance observation study of the distribution of "ice mounds" in the Cape Hatt vicinity in order to establish a correlation between "ice-mound" morphology and wave exposure or sediment texture characteristics.

Provided that the "ice mounds" are found to be formed by groundwater extrusion, then an instrumentation programme, which is designed to monitor freeze-back conditions, should be conducted. Instrumentation should include thermistor probes of at least 2 m in length installed across the intertidal zone, piezometers designed to monitor groundwater pressures, and a self-contained recording mechanism. The recording mechanism is an important component of the instrumentation in that complete freeze-back of the active layer may extend over a period of many months.

The suggested schedule for the "ice-mound" observation programme is:

(a) a pre-melt trenching programme in late May or early June, 1981,

(b) a distribution reconnaissance programme to coincide with the camp opening in mid-July, 1981, and

(c) if necessary, instrumentation installation in spring 1982 with an associated recording programme in fall-winter 1982.

It is also recommended that the freeze-back study be coordinated with similar freeze-back studies being planned by the Geological Survey of Canada (R.B. Taylor, personal communication).